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Gas-Grain Simulation Facility: Aerosol and Particle Research in Microgravity

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Gas-Grain Simulation Facility: Aerosol and Particle Research in Microgravity

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TABLE OF CONTENTS

Acronyms and Abbreviations

ACPL	Atmospheric Cloud Physics Laboratory
AMS	American Meteorological Society
ARC	NASA Ames Research Center
CCD	Charge coupled device
CCN	Cloud condensation nuclei
CNC	Condensation nuclei counter
DRI	Desert Research Institute, University of Nevada System
EID	GGSF Project Experiment Information Database
EURECA	European Retrievable Carrier (a free-flying orbital platform launched from Shuttle)
g	Unit of acceleration equal to 9.8 m/s2
GGSEM	Gas-Grain Simulation Experiment Module
GGSF	Gas-Grain Simulation Facility
He-Ne	Helium-neon
IR	Infrared radiation
ISPR	International Standard Payload Rack
LDV	Laser Doppler Velocimetry
MSFC	NASA Marshall Space Flight Center
OPC	Optical particle counters
PAH	Polycyclic Aromatic Hydrocarbons
PIs	Principal Investigators
PMTs	Photomultiplier tubes
ppm	Parts per Million

RF	Radio Frequency
SSF	Space Station Freedom
SWG	Science Working Group
TEOM	Tapered element oscillating microbalance
USRA	Universities Space Research Association
UV	Ultraviolet Radiation

Executive Summary

The Gas-Grain Simulation Facility (GGSF)

The Gas-Grain Simulation Facility project goals are to serve the needs of the exobiology science community and other disciplines by providing a series of flight opportunities. These flight opportunities would provide access to a microgravity laboratory for conducting research on small-particle (submicron to millimeter size) interactions and would support the needs of exobiologists in their quest to elucidate the origins and evolution of life in the universe. GGSF research would involve studying fundamental processes such as formation, growth, condensation, evaporation, coagulation, and collision of small particles (e.g., crystals, liquid droplets and dust grains), particularly when the phenomena of interest are masked or inhibited in Earth-based (1g) laboratory study. In order to accommodate such research, the project's approach is to develop the GGSF for installation on the International Space Station Freedom as well as to establish early space- and ground-based low-gravity research opportunities prior to completion of the GGSF.

The GGSF will consist of several interchangeable chambers: an ambient temperature; a low temperature; a high temperature; and a low pressure. The chamber, when installed in the Facility, will be supported by subsystems providing such capabilities as chamber environment regulation and monitoring, and computer control and data acquisition. Sample generation and retrieval subsystems will provide handling of experiment materials and products such as liquids, dust, tholins, soots, ices and microbes. Diagnostics such as light-scattering measurement systems, aerosol size-spectrum measurement devices, and optical imaging systems will be included. Additionally, Facility hardware will be designed to an adaptable configuration, allowing the most flexible accommodation of the science requirements and allowing for the future evolution of its capabilities.

The GGSF Science Workshop, 1992

This document reports on the Gas-Grain Simulation Facility (GGSF) Science Workshop co-hosted by NASA Ames Research Center and Desert Research Institute (DRI), University of Nevada System and held at DRI in Las Vegas, Nevada on May 4 through 6, 1992. The purpose of this report is to document the information disseminated at the Workshop; to record the participants' reviews of the Phase A GGSF design concept and of the set of science objectives and technical requirements currently carried by the GGSF project; and, to respond to any questions and concerns that were raised at the Workshop. Specific GGSF project recommendations for the future based on the comments and findings generated by the Workshop are presented below. These recommendations are presented again in Chapter 5 as one-to-one responses to the Workshop findings.

The main objective of this workshop was to bring the science community (potential GGSF experimenters, GGSF staff, and Science Working Group members) and the project hardware developers (Phase A contractor) together to initiate an important dialog aimed at ensuring that the GGSF launched to Space Station Freedom has the best design possible for its intended use. The workshop was a good forum at which to familiarize members of the science community with related research activities and, to this end, both plenary- and poster-session science presentations were given. Additional presentations on the GGSF project goals and history, status, experiment requirements, the Facility design concept, and mission and microgravity constraints set the stage for discussion sessions.

Discussion groups were organized by science discipline, sample generation and handling techniques, and diagnostics. These sessions helped further the process of defining and refining the technical requirements (i.e., the scientists' experiment needs) which translate into functional engineering requirements for the Facility hardware. They also provided feedback from the science community on the Facility design concept study—an initial, top-level attempt to accommodate the science and technical requirements, without conducting detailed design analyses. This report documents the community's response to the GGSF design concept and its concerns regarding the depth and/or breadth of GGSF science objectives and technical requirements.

Workshop Recommendations

Based on the comments and findings generated by the various discussion groups and summarized in this report, the GGSF project makes the following recommendations:

- The GGSF Science Working Group should review and make recommendations to NASA Headquarters on the science goals of the project. These goals should be expanded to encompass, as much as possible, the entire range of research areas for which this facility may be appropriate (see Chapter 2).

- Since the project's success depends on the successful conduct of future GGSF flight experiments, the GGSF science community should be prepared for space-based research by first conducting experiment concept definition studies in ground-based laboratories and by conducting initial small experiments on low-gravity facilities such as drop towers, aircraft (e.g., NASA's KC-135), and Shuttle mid-deck. To that end, the project recommends that the science community be kept apprised of relevant funding mechanisms and, as soon as possible, additional funding should be made available for a microgravity experiment concept development and a small experiments flight program.

- Prior to future GGSF development phases, an in-depth survey (e.g., through a GGSF technology workshop) should be conducted to identify current laboratory procedures used by the GGSF science community and commercially available techniques which are appropriate for the GGSF, and to provide further understanding of and insight into the technical requirements for the GGSF.

- Interested scientists are encouraged to submit strawman experiments to expand the requirements base to which the GGSF will be designed. The project also recommends that the GGSF Science Working Group review all strawman experiments to ensure that the experiments meet GGSF science objectives, require microgravity, and that their technical requirements (as documented in the Experiment Information Database) are feasible for incorporation into facility requirements and represent a specified level of maturity.

- The Experiment Information Database (EID) must be expanded to include new fields/data that better document requirements such as chamber cleanliness. Given the importance of chamber cleanliness to the GGSF design, the project recommends that study and resolution of this issue in particular be given high priority in future design activities. Additionally, funding and research opportunities must be made available to the GGSF science community for further development of GGSF experiment concepts before many requirements "holes" in the EID can be eliminated.

- Parameter ranges in the Experiment Information Database should be reviewed with the intent of accommodating the widest range of research. Any reduction in a given parameter range should only be the result of engineering trade-off studies and should be weighed carefully against science impact.

- Aspects of the Phase A concept design cited at the workshop as insufficient for accommodating the current requirements will be recommended by the project for further study in future Facility development phases.

- Key GGSF subsystem concepts and functions should be tested in low-gravity environments through, for example, a series of sub-orbital or Space Shuttle trials. These flights might serve a dual purpose as engineering concept demonstration flights and as early science experiments.

Project Status–Post Workshop

In the period following the workshop, the project has been subject to significant changes within the Agency. The project is no longer an element of the Space Biology Initiative within the NASA Headquarters' Life Science Division. It is currently an element in the Exobiology Program in the Solar System Exploration Division at Headquarters. Facility and related development activities remain focused in the Solar System Exploration Branch at NASA Ames Research Center. Additionally, the project has been subjected to considerable funding cuts owing in part to the uncertain future of the Space Station Freedom program. These changes in the program prohibit developing and launching the Gas-Grain Simulation Facility by 1998.

These programmatic changes represent a significant impact to the project, yet it is important to note that the fundamental requirement of the project is to provide microgravity research opportunities for the GGSF science community regardless of the vehicle. The long term goal, which the GGSF concept has been developed to address, is to provide extended duration microgravity and human-tended research platforms. Although Space Station Freedom still appears to be the most desirable space platform to meet these goals, there are many other low-gravity and microgravity platforms on which the GGSF science community can make significant advances in developing their science and conducting their research; such platforms include aircraft and drop towers, Shuttle mid-deck, bay, and spacelab facilities, and possibly European facilities such as the free-flyer, EURECA.

The GGSF project is deferring the development of the Gas-Grain Simulation Facility to the end of the decade and instead will re-focus in the near term on providing science experiment development and early science research opportunities on low-gravity and microgravity facilities such as drop towers, aircraft (e.g., NASA's KC-135), and Shuttle mid-deck. To ensure that flight research opportunities are appropriate and will yield high science return requires the creation of a strong terrestrial laboratory-based research program to develop flight experiment concepts and to establish the need, ultimately, of any individual experimenter to conduct his or her research on a space-based platform; such a ground-based research program is now being formed and will go hand-in-hand with plans to develop and implement a small experiments flight program. Development of this important foundation for the Gas-Grain Simulation Facility project will be the primary focus over the next few years.

Conclusion

The activities conducted during the Workshop, the enthusiastic participation of the community as discussion leaders and participants, and the support of the personnel and comfortable facilities provided by the Desert Research Institute (DRI) led to a highly productive and successful meeting. Clearly the Gas-Grain Simulation Facility project benefits greatly from ongoing communication with and participation of the science community at large. More than ever, future workshops convening the GGSF science community are very much warranted to ensure that the important science objectives and research interests of this community are carried forward in NASA planning, and that appropriate ground-based and orbital research opportunities become available as soon as possible.

Acknowledgements

We would like to express our appreciation for the contributions and efforts of the individuals and the organizations which resulted in a successful Gas-Grain Simulation Facility (GGSF) Science Workshop. We particularly wish to acknowledge James V. Taranik, President of the Desert Research Institute (DRI), for co-hosting the Workshop at the Desert Research Institute's facility in Las Vegas, Nevada. Invaluable support from DRI staff was provided, especially in the person of John Gardner II. We would also like to thank Warren Kocmond for sharing the wisdom gained from the ACPL Project with the GGSF project members and the science community; the GGSF Science Working Group members in attendance (see Appendix A); the leaders of our discussion groups, the Plenary Session speakers and the poster session contributors (see Appendices B and C). Special thanks are also due to the science community members who further assisted by reviewing drafts of this report and to the members of the ARC Solar System Exploration Branch who assisted with all the last-minute details of coordinating, generating and reviewing meeting materials. Funding for this activity was provided by the Space Biology Initiative Program Life Sciences of the Division at NASA Headquarters.

We dedicate this publication to the memory of Dr. Thomas W. Scattergood, an Ames Research Center Associate from the State University of New York, Stony Brook. Tom passed away in August 1993, and with his passing we feel the loss of our colleague and friend. Tom contributed much to the Gas-Grain Simulation Facility project, offering scientific knowledge and insight based on the honesty and deep integrity he brought to his research. His honesty and integrity were apparent also in the courage and wonderful sense of humor Tom always brought to Ames Research Center. We are certain that Tom's research on Titan's atmospheric aerosols and the knowledge he passed on to the GGSF project will pave the way for future researchers.

CHAPTER 1

INTRODUCTION

This chapter briefly outlines the Gas-Grain Simulation Facility (GGSF) project objectives and philosophy, describes the goals and activities of the workshop reported on herein, and summarizes the interim results of the GGSF Phase A study to develop an initial design concept for the Facility. It reviews the history of the Atmospheric Cloud Physics Laboratory (ACPL), a shuttle project of the 1970's, and provides the GGSF project and science community with valuable insight into the flight hardware development process. Additionally, the capabilities and constraints of space platforms are discussed for the potential experimenter's consideration in planning flight research.

1.1 PROJECT AND WORKSHOP OVERVIEW

The Gas-Grain Simulation Facility (GGSF) project at NASA Ames Research Center (ARC), until 1993, had been an element within the Program and Flight Missions Branch of the Life Sciences Division at NASA Headquarters. A joint Memorandum of Agreement established the Life Sciences Division in the lead role for the project with the Solar System Exploration Division (planetary science) in a supporting role. A recent reorganization at NASA Headquarters now places the project entirely within the Exobiology Program of the Solar System Exploration Division.

The project goals remain the same: to serve the interdisciplinary needs of the exobiology science community, as well as the needs of other disciplines (e.g., planetary science, astrophysics, and atmospheric sciences), by providing a series of flight opportunities. These opportunities would provide access to a microgravity laboratory for conducting research on small-particle (submicron to millimeter size) and gas-particle interactions, and would support exobiology's goal to understand how cosmic, solar system, and planetary evolution have influenced the origin, evolution, and distribution of life and life-related molecules in the universe. In particular, the laboratory research enabled by the GGSF would involve simulating and studying fundamental chemical and physical processes such as formation, growth, condensation, evaporation, coagulation, collision and mutual interaction of small particles (e.g., crystals, powders, liquid droplets and dust grains). Chapter 2 describes the science goals and objectives of the GGSF project in greater detail.

The project's approach or philosophy is to accommodate basic small-particle and aerosol research by developing the GGSF for installation on Space Station Freedom (SSF) and by establishing early space- and ground-based low-gravity research opportunities prior to completion of the GGSF. Further, to ensure that flight research opportunities are appropriate and will yield high science return requires creating a strong terrestrial laboratory-based research program to develop flight experiment concepts and to establish the need, ultimately, for an experimenter to conduct his or her research in space. The Facility itself, which will occupy a standard SSF rack, will consist of an experiment chamber(s) supported by subsystems providing such capabilities as chamber environment regulation and monitoring, sample generation and retrieval, and computer control and data acquisition. Diagnostics such as light-scattering measurement systems, aerosol size-spectrum measurement devices, and optical imaging systems will be included. Additionally, Facility hardware will be designed to have an adaptable configuration, allowing the most flexible accommodation of the science requirements and allowing for the future evolution of its capabilities. Section 1.2 below describes the current design concept for the Facility.

To identify the need for the GGSF and to define and develop requirements for this Facility, NASA has conducted several workshops; one held in 1985 [14] which established the science rationale and objectives for the project, and another held at Ames Research Center in 1987 [2] which began the process of defining potential (or strawman) experiments for the GGSF and their associated technical requirements. Efforts since then have resulted in the compilation of "strawman" technical requirements into a GGSF Experiment Information Database (EID) which formed the basis for a Facility concept design study. Chapters 3 and 4 describe these requirements. Appendix D also contains summaries of the "strawman" experiments currently carried by the project.

Most recently, the GGSF Science Workshop, co-hosted by NASA Ames Research Center and the Desert Research Institute (DRI), University of Nevada System was held at DRI in Las Vegas, Nevada on May 4 through 6, 1992 (see Appendices A and B for the agenda and participant list). The main objective of this meeting was to bring the science community and the project hardware developers together to initiate an important dialog which must continue through all hardware development phases to ensure that the "right" GGSF is launched to Space Station Freedom. As part of that dialog, the workshop served to further the process of defining and refining the technical requirements (i.e., the scientists' experiment needs) which will then be translated into functional engineering requirements for the Facility hardware. It also afforded the opportunity to get preliminary feedback from the science community on the Facility design concept study—an initial, top-level attempt to accommodate all of the Facility requirements, without yet conducting detailed design analyses. Chapters 2, 3, and 4 document the community's response to the GGSF design concept and its concerns regarding the depth and/or breadth of GGSF science objectives and technical requirements. Another important goal of the workshop was to familiarize members of the GGSF Science Working Group and science community with related research interests and activities. Science presentations were made during the plenary sessions and via a poster session. Abstracts for these presentations are published in Appendix C.

This report documents the most salient points that emerged from the technical discussion groups and should serve, in particular, as a guide to the project on issues which should be studied and addressed in future development stages. In this vein, Chapter 5 presents the project's response to the workshop technical discussions by outlining steps it can take to address the findings of our science community.

1.2 GGSF Concept Design

NASA flight hardware is developed in four phases: Phase A, in which a concept design study is undertaken; Phase B, in which a systems performance definition study is completed and a preliminary design developed; and, Phase C/D in which the system design and development are completed and the hardware is fabricated, tested, and launched. An aerospace firm, TRW Space and Technology Group of Redondo Beach, CA, has been conducting the GGSF Phase A study. The objectives of this study are:

1) to review science and technical requirements and to develop the Facility's functional requirements, conduct design analyses and trade-offs, and develop a GGSF concept design for flight on Space Station;

2) to develop a concept design for a Gas-Grain Simulation Experiment Module (GGSEM) for flight on Space Shuttle. The GGSEM would accommodate a subset of GGSF experiment objectives, provide for early science return, and allow testing of key GGSF hardware technologies in microgravity; and

3) to develop and deliver a laboratory breadboard of a key GGSF hardware component.

A broad set of experiments, outlined during the 1987 GGSF workshop [2] and refined in a recent survey, were used to scope out the technical requirements (e.g., environment and diagnostic needs) for the Facility. These requirements have been compiled into a database, the GGSF Experiment Information Database, which forms the basis for the science and technical requirements summarized in Table 1.2–1.

Table 1.2–1. Summary of the Science & Technical Requirements

Chamber pressure	From 10^{-12} to 3 bars, with desire to reach 10 bars
Chamber temperature	From 40 to 1,200 K, with desire to reach 4 K
Chamber volume	From 100 cm^3 to a hundred liters, various geometries
Particulate type	Liquid aerosols, solid powder dispersions, soots from combustion, high-temperature condensates (nucleation of metal and silicate vapors), low-temperature condensates (ices of water, ammonia, methane, or CO_2), single liquid droplet, single/few particles, in situ generated by UV radiation
Particulate size	From 10 nm to 3 cm
Particulate concentration	A single particle to 10^{11} particles per cm^3
Gases required	Air, N_2, He, H_2, Ar, Xe, H_2O, CO_2, CO, NH_3, CH_4, etc.
Diagnostics required	In-line optical systems and off-line sample analysis, including measurements of grain strength, mass, density, charge, and geometry; grain size distribution, number density, optical properties (index of refraction, emission/absorption spectra); imaging; particle kinematic parameters before/after a collision
Experiment duration	Seconds (collisions) to weeks (aerobiology experiments)

A more extensive description of requirements can be found in Chapters 3 and 4. Based on the science and technical requirements, trade-off analyses were performed and a common grouping of functional requirements established. Possible technical approaches were identified and evaluated to form a Phase A GGSF conceptual design.

Providing a broad range of capabilities that satisfy most of the science and technical requirements, the GGSF concept, depicted in Figure 1.2–1, consists of several subsystems configured within a Space Station Freedom International Standard Payload Rack (Table 1.2–2). The design concept incorporates (one at a time) four interchangeable chambers (Figure 1.2–2) which can accommodate the ranges of pressures, temperatures, and experiment volumes described in Table 1.2–3. Optical ports for light sources, video cameras, and diagnostics, as well as physical ports for sample injection and removal, electrical feedthroughs, and environment control are integrated into each chamber.

Figure 1.2–1. GGSF Concept Model

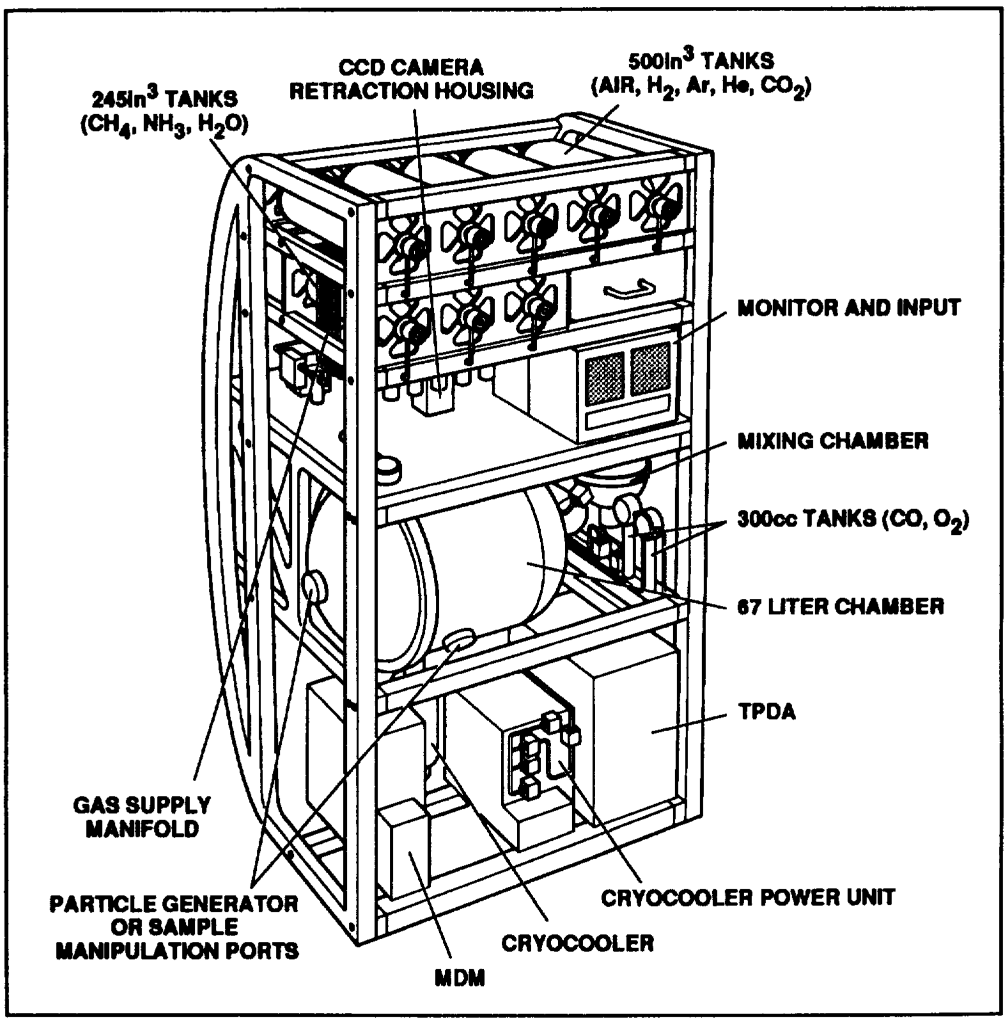


Table 1.2–2. International Standard Payload Rack Features

Physical dimensions	Maximum depth 75 cm, height 164 cm, width 93 cm
Payload volume	~1.13 m^3
Weight capacity	700 kg
Electrical power	3 or 6 kW peak, depending on rack location
GN2 supply	99.5% purity by volume (min), 0.5% O_2 by volume (max), 58 ppmv* (max) hydrocarbons, 26 ppmv (max) moisture
Vacuum exhaust	Waste management under strict control of allowable waste gases and contaminants
Vacuum vent	Provide vacuum down to about 10^{-6} bar
Avionics air	About 1 kW cooling capacity
Cooling water	Two loops of cooling water, one at a low temperature

* parts per million by volume

Figure 1.2–2. Experiment Chamber Concept

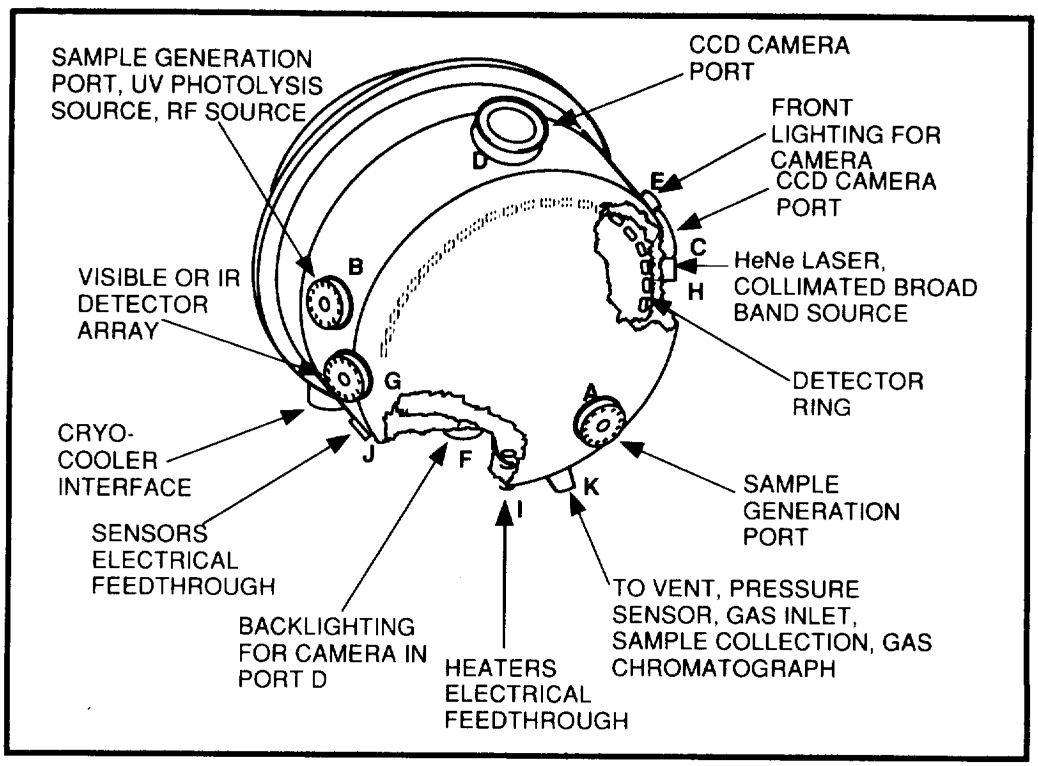
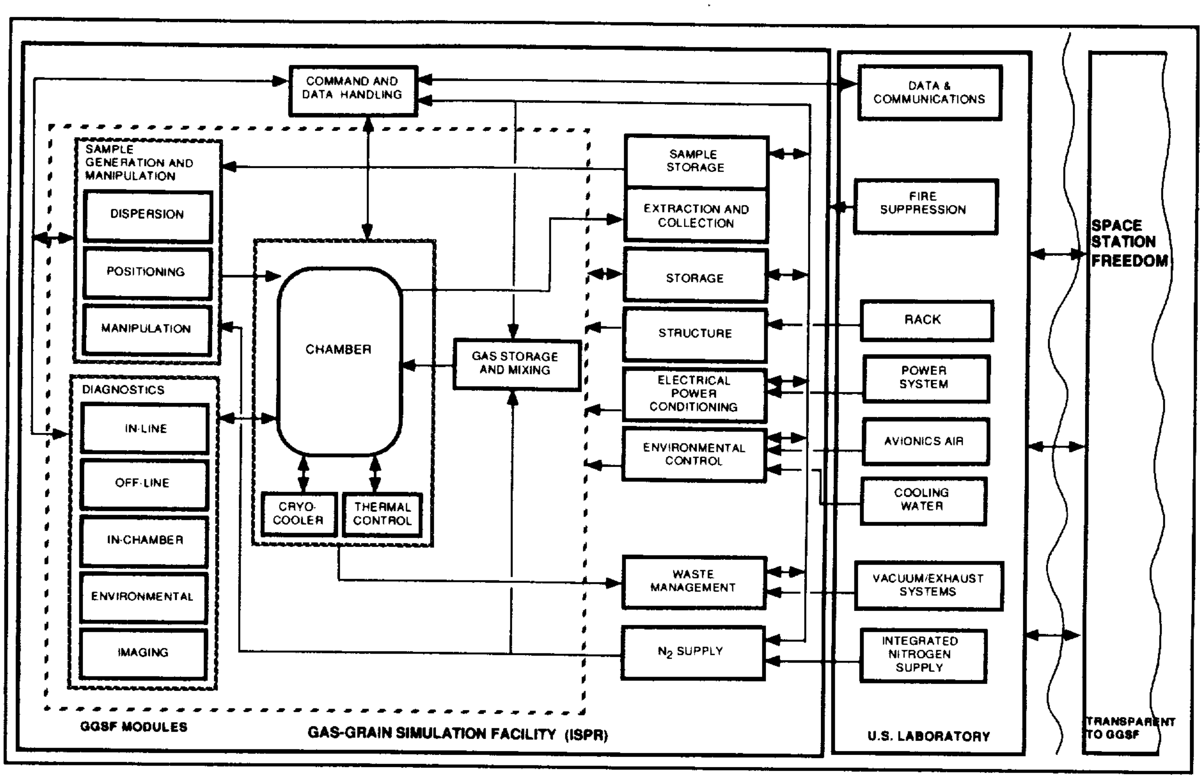


Table 1.2–3. GGSF Chamber Concepts

Chamber	Volume (liters)	Pressure (bar)	Temperature (K)
Large volume	67	10^{-6}–1	150–400
Low-temperature	4.2	10^{-6}–3	60–400
High-temperature	8.2	10^{-6}–1	300–1200
High vacuum	4.2	10^{-10}–1	60–400

GGSF concept design sub-systems provide command and data handling, electrical power distribution, and waste management. Additionally, sample generation and handling, diagnostics, environment control (temperature, pressure, gas composition, humidity) and gas storage and mixing assemblies are included. The particle or sample types required (Table 1.2–1) indicate the need for a flexible design configuration so that different sample generators (e.g., liquid aerosol generators, powder dispersers, furnaces) can interface with the chamber as needed. Likewise, the need to provide for light scattering measurements, aerosol size spectrum analyses, and a variety of other diagnostics suggests the use of standardized interfaces, so that the instruments required for a particular experiment or sequence of experiments may be incorporated into the Facility as needed and later be replaced by other instruments when a different set of diagnostic capabilities is called for. Figure 1.2–3 illustrates, in block diagram form, the components of the GGSF system, and the interfaces with the payload rack and associated utilities provided by the U.S. Laboratory on Space Station.

Figure 1.2–3. GGSF Overall System Block Diagram



The GGSF Phase A conceptual design described here is a first top-level attempt at designing a research facility which could accommodate the science and technical requirements derived from the science objectives of a wide variety of experiments. A further step in this Facility development includes the review of the conceptual design with the science community and the GGSF SWG to further clarify the existing science and technical requirements as well as to identify any shortcomings of the design. The workshop reported on herein represented an important first step in that review process, and initiated a dialog between the hardware developers and the science community—a dialog which is critical to all stages of the design and fabrication of a scientifically relevant and viable facility.

A more detailed summary of the GGSF concept study is presented in Appendix E [9]. Additionally, the complete results of the Phase A study with TRW will be documented in three NASA Contractor Reports. The first report [8] covers the Facility technical science and mission requirements. The second report [16] describes a conceptual design for the GGSF. The third report [17] includes the Contractor's concept for a Gas-Grain Simulation Experiment Module designed to fly in a Shuttle mid-deck double locker which accommodates a modest subset of GGSF science requirements; the development of a solid particle generator laboratory breadboard is discussed as well.

1.3 HISTORICAL PERSPECTIVE: THE ACPL

The following is a review of the Atmospheric Cloud Physics Laboratory (ACPL), a former NASA Spacelab facility program which was initiated in 1973 and cancelled in 1979. ACPL is relevant to the GGSF because of similarities in the proposed science and the hardware designed to respond to scientific requirements.

ACPL was designed to provide particle generators, experiment chambers, and diagnostic and detection instruments required by atmospheric scientists for studies of the formation and growth of ice and liquid water cloud particles, and physical and chemical processes which affect such particles. Ideas for low-gravity experiments had begun accumulating in the late 1960's, associated with research problems in fields such as weather modification and cloud modeling. Low gravity was seen to be an advantage in minimizing the deposition of large (greater than a few micrometers) particles and in reducing convection in chambers.

The ACPL Program entered Phase A in 1973, Phase B in 1976, and Phase C/D in 1977. The Program was sponsored by the former Office of Applications at NASA Headquarters and ACPL project work was overseen by Marshall Space Flight Center in Huntsville, Alabama. The purposes of this section are to briefly summarize the history of the ACPL effort, to indicate its technological heritage relevant to the GGSF and, from its perspective, to pass on recommendations to the GGSF project and its science community.

1.3.1 ACPL Overview

Phase A

The ACPL Phase A Feasibility and Definition Studies were conducted by the McDonnell Douglas Astronautics Company, Huntington Beach, California, in 1973 and 1974. The Feasibility Study led to the identification of 21 candidate experiments arising from discussions with about 50 atmospheric scientists. These experiments addressed a range of problems relevant to cloud physics at that time, such as identifying the mechanisms responsible for the nucleation of ice and liquid water particles in terrestrial clouds. In the Laboratory Concept Definition Study, six experiment chambers were proposed in response to these experiment requirements along with seven particle generators and nine detection and diagnostic devices. The first launch of ACPL was anticipated for late 1980 as a Space Shuttle (Spacelab) payload.

ACPL Phase B

The ACPL Phase B Final Definition and Preliminary Design Study was conducted in 1976 by the General Electric Company, Space Division, King of Prussia, Pennsylvania, and by the TRW Defense and Space Systems Group, Redondo Beach, California. Each Phase B contractor conducted the study in response to scientific requirements identified in Phase A; these requirements for experiments involving water and ice nuclei and the formation of water droplets and ice particles, were addressed by designing the ACPL to include three experiment chambers and three scientific subsystems. The three experiment chambers combined many of the functions identified in Phase A, operating over the -25 to +30° Celsius temperature range, and generating saturation ratios from 0.3 to 1.12 (i.e., from 30% relative humidity to 12% supersaturation). They were designated the Expansion Chamber, Continuous Flow Diffusion Chamber, and Static Diffusion Chamber, and their characteristics are shown in Table 1.3–1.

Table 1.3–1. ACPL Chamber Characteristics

	Expansion Chamber	Continuous Flow Diffusion Chamber	Static Diffusion Chamber
Dimensions	Radius 20 cm; length 27 cm (34 liters)	65 cm x 40 cm x 2 cm	Radius 12.5 cm, height 2 cm
Temperature range [°C]	-25 to +30	-25 to +30	-25 to +30
Wall temperature uniformity [°C]	0.1	0.01	0.01
Relative humidity range [%]	30 to 99	100 to 104 (4% supersaturation)	100 to 110 (10% supersaturation)
Data collection (diagnostics)	Photographic	Optical Particle Counter	Photographic
Droplet counting accuracy	± 3%	± 3%	± 12%
Special features	Adjustable gas expansion rate and wall temperature cooling rate	Temperature gradient between parallel plates creates supersaturation in continuous flow	Temperature gradient creates supersaturation; samples in "batch" process

Scientific subsystems included water-soluble and insoluble aerosol particle generation, aerosol particle counting and characterization, and droplet and ice particle optics and imaging. Major science drivers were identified, including saturation ratio accuracy requirements, especially in the Expansion Chamber where the humidity profile is a function of the gas expansion rate, the wall temperature profile, and the rate at which water condensation takes place upon nuclei. The Phase B Final Reviews were held at MSFC in December, 1976.

During the period from March, 1976, to April, 1977 MSFC also funded Universities Space Research Association (USRA) in Boulder, CO to assist in the identification of scientific functional requirements for ACPL and to identify interested potential Principal Investigators (PIs) and candidate experiments. Approximately 600 scientists responded to USRA's inquiries and, of these, 150 were described as "highly interested" in the facility. USRA funded nine small concept studies during this period, for experiment and subsystem development.

ACPL Phase C/D

The ACPL Phase C/D Design and Development Contract was awarded to the General Electric Space Division and conducted from 1977 until 1979. NASA's Statement of Work called for the design, development, fabrication, delivery and operational support of a "protoflight" ACPL, meaning that the same unit used for system qualification testing would also be flown. The experiment chambers and scientific subsystems remained as identified in Phase B.

During this period NASA also selected and funded Principal Investigators (PIs) for the development of experiments which would fly on the first ACPL mission, ACPL–1, scheduled for late 1980, and on a subsequent mission, ACPL–2. These eleven investigators were funded after their submission of proposals in response to a NASA Announcement of Opportunity in early 1977; the PIs and their experiments are listed in Tables 1.3–2 and 1.3–3.

Table 1.3–2. ACPL-1 Principal Investigators

Investigator	Experiment
Dr. P. Squires Desert Research Institute Reno, Nevada	Cloud Forming Experiment
Dr. D.E. Hagen University of Missouri Rolla, Missouri	Droplet Growth; Heat Transfer in Cloud
Dr. J. Hallett Desert Research Institute Reno, Nevada	Ice Crystal Growth
Mr. W.C. Kocmond Desert Research Institute Reno, Nevada	Cloud Forming Experiment; Complex Aerosol Nucleation
Dr. B.J. Anderson, Mr. O.H. Vaughan NASA Marshall Space Flight Center Huntsville, Alabama	Adiabatic Response Time; Ice Crystal Growth; Turbulence Decay

Table 1.3–3. ACPL-2/3 Principal Investigators

Investigator	Experiment
Dr. P. Hobbs University of Washington Seattle, Washington	Sulfate Conversion
Dr. C.P.R. Saunders University of Manchester Manchester, England	Supercooled Droplet Freezing
Dr. G. Vali University of Wyoming Laramie, Wyoming	Ice Crystal Growth in Supercooled Cloud
Dr. L. Eaton General Electric Company Valley Forge, Pennsylvania	Diffusion and Phoretic Forces
Dr. C.A. Knight National Center for Atmospheric Research Boulder, Colorado	Ice Crystal Growth in Supercooled Cloud

By mid-1979, the GE Team had completed designs for all the chambers and subsystems and had conducted a Preliminary Design Review (May, 1978), a Detailed Subsystem Review (November, 1978), and an Interim Design Review (June, 1979) with MSFC and the PIs. Testing of laboratory versions of some of the ACPL subsystems, such as the soluble particle generator, had begun at GE and at some of the PI laboratories under NASA sponsorship; a prototype continuous-flow diffusion chamber was being constructed at Desert Research Institute. The GE Team completed a Critical Design Review in October, 1979, although, prior to this point in the ACPL Program, major problems were apparent.

By about the middle of FY'79, NASA Headquarters' perception of the ACPL Program was that the projected cost to complete ACPL–1 was rising from the initial estimate of approximately $7M to more than $20M. Concerns about unproven technology were also raised, especially regarding the expansion chamber. As early as March, 1979, the PIs were informed that the Program was being re-evaluated by Headquarters. The initially planned 1980 launch schedule for ACPL–1 was cancelled, and a number of options for delays and phased development were proposed in a "restructuring" effort. At the same time, scientific advocacy was strong and resulted in supporting efforts such as an open letter in the January, 1979 issue of the *Bulletin of the American Meteorological Society* (AMS), authored by the Chairman of the AMS Cloud Physics Committee as well as USRA and ACPL scientists, pointing to the scientific worth of the facility. The ACPL PIs argued for restructuring options which preserved the expansion chamber and included minimizing delays in flight scheduling. The use of some of the instruments developed in university laboratories as flight hardware in order to reduce costs was discussed. These options were considered over a period of several months, but Headquarters' decision to cancel ACPL as a facility program was announced in late 1979. In May, 1980, USRA and NASA hosted a meeting of an ad hoc panel of nine atmospheric scientists in Boulder, Colorado, in order to obtain their recommendations for future NASA-sponsored cloud physics research. This discussion resulted in a meeting minutes document which was published as a USRA report.

1.3.2 ACPL Relevance to the Gas-Grain Simulation Facility

The ACPL effort is relevant to the GGSF program in at least three general areas: first, some of the terrestrial cloud physics experiments are still relevant, and could be candidates for GGSF; second, some of the aerosol generator, experiment chamber, and diagnostic technology considered for ACPL is relevant to GGSF experiment requirements; and third, the overall conduct of the ACPL Program can be studied to extract lessons relevant to GGSF in terms of planning a successful program, and thus avoiding any pitfalls. Figure 1.3–1 shows the completed design study, hardware and software products of the ACPL Program.

Figure 1.3–1. Products of the ACPL Program

A. ACPL Facility Subsystem Designs:
   1. Expansion Chamber
   2. Continuous Flow Diffusion Chamber
   3. Static Diffusion Chamber
   4. Optics and Imaging
   5. Aerosol Generation

B. Analytical Mathematical Treatment of Chambers and Aerosol Transfer and Injection (P. Squires)

C. ACPL Chamber Numerical Simulator Software

D. Prototype Hardware:
   1. Static Diffusion Chamber (flown on KC–135)
   2. Continuous-Flow Diffusion Chamber
   3. Aerosol Generators—Aqueous and Photolytic
   4. Water Vapor Saturator

E. Glow Discharge Chamber Cleaning Facility

Some immediate comparisons of the two programs can be made. One of the limitations of ACPL was that it had to be planned in order to utilize a very limited number of available Spacelab flights, whereas GGSF is conceived as a long-duration Space Station facility. Once GGSF is operational, this should allow much greater flexibility and many more opportunities for its use. The ACPL was also limited in terms of the scientific community it addressed; the terrestrial cloud physics community could muster its scientific advocacy for ACPL; but since the scientific support for GGSF is much more diverse, advocacy should be correspondingly stronger. Another prominent difference is in terms of PI support philosophy; ACPL flight PIs were chosen at a relatively early stage in the program, in 1977. There was some feeling that this allowed individual PIs to become entrenched regarding their experiment requirements, and to demand that difficult engineering tasks be undertaken by the Phase C/D hardware contractor, leading to escalating costs. The GGSF approach is to select flight PIs at later stages, and only after successful Earth-gravity experiment definition studies have been completed.

1.3.3 ACPL Recommendations

Several recommendations for GGSF can be made based on the ACPL experience:

- Be thorough but realistic in developing and stating technical requirements. The flexibility to accommodate wide ranges of requirements is attractive, but can lead to unknown costs.
- Avoid wish-lists that exceed state-of-the-art capabilities; again, these can lead to unpredictable development costs.
- Provide funding for evaluation of experiments and support instrumentation development in the terrestrial laboratory before locking into a facility design.
- PIs must be willing to compromise in order to help control costs.
- Maintain trustworthy communication between NASA Headquarters, the GGSF project at Ames Research Center, and TRW or any other contractor.
- Cultivate Headquarters' support during NASA administrative changes.
- PIs need to work together, or through a representative, to address concerns and to maintain a unified stance.

1.3.4 ACPL Bibliography

The information presented here on the ACPL project and science was compiled with the help of Prof. Warren Kocmond. Additional information on this project and its products can be found in the following documents:

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1.4 MICROGRAVITY CAPABILITIES AND CONSTRAINTS

Every low-gravity research environment offers special capabilities, but an orbiting microgravity experiment facility can offer unique capabilities unavailable in any Earth-based or sub-orbital low-gravity facility. These advanced capabilities include the following:

- Low settling rates for suspended particles over extended periods of time;
- Extended periods of time with very low levels of buoyancy-driven convection;
- Ability to study low-energy interactions that may be masked by gravitational forces on Earth;
- Ability to study fractal particles and other objects that are gravitationally unstable at Earth gravity (1 g).

In addition to these advanced capabilities, a microgravity experiment environment has limitations which an Earth-based laboratory does not have; limitations which must be considered when designing effective microgravity experiments. These limitations fall into two major categories: those due to the NASA crewed space platform, and those due to properties of the low-acceleration environment itself.

1.4.1 Capabilities not Available on Earth

Earth-based and sub-orbital research facilities offer a vast range of experiment capabilities but, in the area of low-gravity research, they are somewhat limited. The major advantages of an orbiting research facility derive from the levels and durations of the accelerations. Drop towers and tubes offer very low acceleration levels, but the available experiment durations are less than six seconds. Learjet and KC–135 aircraft flying parabolic trajectories offer experiment durations of up to 30 seconds, but only attain accelerations as low as 10^{-2} g. Sub-orbital rocket flights (sounding rockets) can achieve acceleration levels as low as 10^{-4} g for as long as 14 minutes [15]. An orbiting laboratory, on the other hand, would offer an experiment environment with accelerations on the order of 10^{-5} g or lower for several days. These long durations of low accelerations offer several important experiment capabilities that cannot be achieved in Earth-based laboratories. These are discussed below.

Particle Suspension Times

Suspending particles in a gas for extended periods of time in an Earth-based laboratory is not a trivial task. While very small particles will be slowed by air viscosity, particles larger than about 0.1 mm in radius in STP air will fall nearly ballistically with an acceleration of 1 g. An experiment requiring suspension of particles is limited in duration by the dimension of the experiment chamber in the direction of the acceleration, the magnitude of the acceleration, the density and viscosity of the suspending gas, and the mass and aerodynamic size of the particles. For example, in the absence of convection a water drop 10 μm in radius will take about 10 seconds to settle 10 cm in STP air in a 1 g environment, while in a 10^{-5} g environment it would take about 10 days to settle the same distance. The increase in particle settling times is caused by a decrease in the particle's terminal velocity, which effectively increases the aerodynamic similarity in particles of different sizes. This increase in aerodynamic similarity reduces the amount of gravitationally induced "scavenging" of single particles or small aggregates by larger aggregates, and increases the likelihood (over longer periods of time) of other interactions (e.g., Brownian aggregation) between clusters of different sizes. Such an environment would be useful in, for example, aggregation experiments in which the physical characteristics of the aggregate (e.g., fractal dimension) are to be determined. In this example, the fractal dimension of an aggregate formed from the interaction of two similarly sized aggregates is different from that of an aggregate formed from the interaction of an aggregate and a single particle [11]. For such experiments, an environment that artificially favors interactions between particles of similar sizes (or of dissimilar sizes) would artificially influence the fractal dimension of the resulting aggregates.

Durations of low acceleration offered by Earth-based and sub-orbital low-gravity research facilities are not sufficient for many experiment investigations on suspended materials. For example, an investigation into coagulation rates of aerosol particles may require an experiment duration of several days to achieve a measurable amount of particle growth. Another example would be an investigation into the structure of large agglomerates formed from constituent aggregates of a variety of sizes. Development of an orbiting laboratory that would offer accelerations on the order of 10^{-5} g for several days' duration would tremendously increase capabilities for research on suspended materials.

Buoyancy Driven Convection

According to Fuchs [7], a gas in contact with a vertical wall that is warmer by an amount ΔT will develop a vertical flow with maximum velocity at height z given by:

$$U = 0.55 \sqrt{g\ z\ \alpha\ \Delta T}$$

where α is the thermal expansion coefficient of the gas ($\alpha \sim T^{-1}$), and the gravitational acceleration is vertically downward (in the $-z$ direction). Since the velocity of convective flow is proportional to the square root of the magnitude of the gravitational acceleration, a low-gravity experiment environment with gravitational acceleration of 10^{-5} g can achieve only 0.3% of the buoyant convective flow velocity of a similar experiment on Earth.

A quiescent fluid is also more likely to remain quiescent in microgravity than in an Earth gravity environment. This stability is indicated by the Rayleigh number:

$$Ra \equiv \frac{\alpha\ \Delta T\ g\ L^3}{\nu\ \kappa}$$

where L is the characteristic length of the chamber, ν is the kinematic viscosity, and κ is the thermal diffusivity. Buoyant convection will not begin unless the Rayleigh number exceeds a critical value. Since the Rayleigh number is directly proportional to gravitational acceleration, in a low-gravity environment it is easier to achieve a Rayleigh number lower than the critical value, thus preventing buoyant convection.

Low-Energy Interactions

An orbiting microgravity laboratory would enable research on low-energy effects that are difficult or impossible to study on Earth. An example of this concerns fractal aggregate structures thought to exist in circumstellar and interstellar environments [13]. The bonds that hold these aggregates together are sufficiently weak that the structures collapse under their own weight in an Earth-gravity laboratory. Another example is the study of low-velocity collisions. Although a great deal of work in this field has been done on Earth by counteracting gravitational forces with compound pendulums, data on the conversion of linear momentum to angular momentum in these collisions cannot be obtained from these pendulum experiments due to the restricted motion allowed by the pendulums (see Appendix C, *Particle Dynamics in Ring Systems: Limitations of Earthbound Experiments*, F. Bridges).

1.4.2 Constraints of Microgravity Experimentation

Low-gravity experimentation differs from Earth-based research not only in capabilities, but also in limitations. One of these limitations is the investigator's inability to perform the experiment "hands-on" being forced instead to depend on an astronaut, a remote-control system, or an automated experiment control system. Most of the experiment constraints of the low-gravity environment fall into two categories: constraints imposed by NASA regulations and capabilities, and constraints due to the physics of a low-gravity environment.

Constraints of a NASA Crewed Platform

Some constraints imposed by NASA on space platforms occupied by human crews fall into the following categories: resource constraints, safety constraints, operational constraints, and fiscal and scheduling constraints. Most of the resource constraints for Space Station Freedom reflect the size of the Space Station. The rack into which an experiment facility can be installed has a volume available for Facility hardware of approximately one cubic meter. The maximum power available to any facility rack is either 3 or 6 kW, depending on the rack's location. This maximum power may not be available at any arbitrary time, therefore power consumption will need to be carefully scheduled to allow the most efficient allocation of this precious resource among Space Station operations and facilities. Resupply opportunities will be limited to scheduled Shuttle flights, perhaps 4 or 5 per year, and the Shuttle's launch load capabilities will limit the resupply mass and volume allocations. Data communications for science payloads (with the exception of safety-critical data) will have lower priority than "mission critical" data, and will be tightly scheduled to ensure an equitable distribution of this important resource. This means that "real-time", or near-real-time, data transmission may be difficult to arrange. Most of these issues may be overcome by developing the Facility and the experiments to allow flexibility in the delivery times of required resources, so that scheduling these resources is not as difficult. For example, an experiment time-line that requires data transmissions within a few hours of important experiment events would be much more likely to fit into the Station's transmission schedule than would a time-line requiring immediate data transmission as these events occur.

The safety constraints that impact an experiment design involve hazardous materials such as cryogens or toxins. These materials will require special containment and handling procedures (with significant associated financial costs) which may in many cases outweigh their utility. Operations constraints involve the limits on astronaut procedures required to perform an experiment. The crew of Space Station Freedom will be small: only four astronauts will be available for payload operation. If there were only 24 payloads, this would give an average of less than six hours of astronaut time to each payload per week (assuming 40-hour work weeks and equal priority for all facility racks). Clearly, a good experiment time-line should minimize astronaut interaction requirements. Scheduling and fiscal constraints must also be considered when designing an experiment, especially when experiment-specific hardware is required. The risk to schedule and budget associated with developing flight hardware is least for items that require fairly minor modifications to existing flight hardware, greater for items requiring flight qualification of commercially available hardware, and greatest for items that require development of new technology. The level of risk involved in implementing a research study will probably be an important consideration in the experiment selection process.

Constraints of Low Gravity

Some aspects of the low-gravity experiment environment itself can be considered constraints, since they require procedures and equipment that are significantly different from those required in a terrestrial laboratory. This is a case of a benefit becoming a liability. For example, while gravitational settling and convection are reduced by moving an experiment from an Earth-based to a microgravity environment, Brownian diffusion is not. Given enough time, diffusion will transport all aerosol particles to the experiment chamber walls where they will be effectively removed from the system. In a shorter time frame, diffusion will create spatial non-uniformity in the particle concentrations, which in turn will create spatially non-uniform particle aggregation rates. These effects can be fairly minor on Earth where large experiment chambers are feasible and homogeneous mixing is easily achieved. In an orbiting facility, however, the launch costs require a facility design that minimizes volume and mass, and homogeneous mixing is harder to achieve (since buoyant convection is more difficult to initiate and flow velocities for buoyant convection are much smaller than on Earth, as discussed in section 1.4.1). These diffusion effects will influence the outcome of an experiment, but knowledge of the effect can still allow meaningful data to be extracted.

There are many instances where objects in microgravity behave in ways that an Earth-bound scientist does not anticipate. An example of this is one research group's attempt to conduct a particle aggregation study on the KC–135 aircraft flight [12]. During the low-gravity phases of the flight the particles would not disperse to achieve an acceptable initial condition for the aggregation experiment. The particle dispersion method depended on gravity in a way that was not obvious before the experiment began. Discovering these "hidden" gravity dependencies and eliminating them is an important part of developing a microgravity experiment.

1.4.3 Microgravity Summary

Scientific research in an orbiting experiment facility must be performed in a very different way from research in a terrestrial laboratory, due to a variety of constraints and limitations. Some of these constraints and limitations derive from NASA regulations on safety, size and power limitations of the orbiting platform, and possible schedule conflicts with higher priority activities. Others derive from the physics of the low-acceleration environment itself. Most of these constraints do not seriously impact the special capabilities of this research environment, capabilities that are not available in any Earth-based or sub-orbital experiment facility. Nonetheless, all aspects of the microgravity environment must be considered in developing an experiment and in defining experiment requirements for a crewed, microgravity platform such as the Shuttle or Space Station Freedom.

CHAPTER 2

GGSF SCIENCE GOALS

This chapter presents the science goals for the Gas-Grain Simulation Facility (GGSF) as they relate to several scientific disciplines. As these goals have changed little since the previous GGSF workshop in 1987, much of the presentation of the GGSF science goals in this chapter is excerpted from the NASA conference report documenting the 1987 workshop. The science categories presented (Biology and Exobiology; Planetary Science; Atmospheric Science; and Astrophysics, Chemistry and Physics) correspond to the four discussion groups convened at the 1992 GGSF Science Workshop. These discussion groups generated findings on the completeness and appropriateness of the GGSF science goals, the scope of the collection of "strawman" experiments from which the technical requirements are derived (see Chapters 3 and 4), and the suitability of the concept design (see Chapter 1) for each science category. The GGSF science goals and the workshop findings for each science category are presented in the following sections.

2.1 BIOLOGY AND EXOBIOLOGY

2.1.1 GGSF Science Goals in Biology

There are two main areas of study in biology that will benefit from low-gravity (microgravity) experimentation. The first is the field of gravitational biology, the study of the effects of "weightlessness" on vertebrates. A primary goal in this area of study is to understand the mechanisms underlying bone decalcification and muscle atrophy at the cellular level so that corrective measures can be taken to reduce the detrimental physical effects of long-duration space flights thus extending human space exploration potential. The second area—the area relevant to the GGSF—is the field of aerobiology, the study of the viability of airborne organisms (e.g., microorganisms).

Airborne microbes in the Earth's atmosphere originate from soils, animals, plants, and bodies of water. They may be pathogenic or non-pathogenic. The major questions in the field of aerobiology concern the viability of airborne organisms, whether they might multiply and grow in an aerosol, and what properties (of the organism and of the air) influence the organism's viability or growth rate. Field studies of airborne microbes in the Earth's atmosphere do not allow isolation of variables (e.g., humidity, temperature, exposure to ultraviolet radiation, trace gases), any of which could influence microbe viability. Controlled laboratory experiments are required to separately investigate the influence of each of these variables.

The survival or growth of organisms suspended in air is related to the length of time for which they are suspended. Achieving significant suspension times in terrestrial laboratories is difficult at best. Stirred settling chambers such as a rotating drum experiment chamber are useful for extending suspension times in terrestrial laboratories, but even these are unable to keep the microbes aloft for much more than a few days [1]. The GGSF will achieve long-duration particle suspension times without additional outside forces acting on the organisms by providing an environment in which the gravity vector is orders of magnitude smaller than on Earth. This will make the GGSF a valuable tool for aerobiology research.

2.1.2 GGSF Science Goals in Exobiology

The GGSF science goals are discussed in detail in the report of the 1987 GGSF science workshop. Following is the discussion of exobiology science goals for the GGSF from that report:

> Exobiology is the study of life in the universe. Exobiologists strive to understand the origin and distribution of the biogenic elements (C, H, N, O, P, S) and the relationship between the Solar System's physical and chemical evolution and the appearance of life. Exobiology research includes tracing the history of organic matter in the primitive Solar System and evaluating the significance of abiologically produced organic matter in the evolution of the terrestrial planets. It is an interdisciplinary field and as such incorporates many aspects of the other disciplines interested in the GGSF. However, exobiology brings a different perspective to the astrophysical, biological, and geological phenomena discussed herein. Often, this perspective involves the study of trace constituents such as the organic components of meteorites or the study of minor chemical processes such as the abiotic production of organics by lightning. These investigations and related experiments were discussed at length in the Exobiology in Earth Orbit Workshops held at Ames in August 1984 and April 1985....
>
> Interactions among gases and grains are fundamental to theories on the origins of the constituents of interstellar clouds, comets, meteorites, interplanetary dust, and Solar System bodies. Interactions between a gas phase and a solid phase include sorption phenomena, heterogeneous catalysis, and many other familiar terrestrial physical, and chemical processes. Such interactions in space may play important roles in the cosmic history of the biogenic elements and compounds. Elucidation of this history involves tracing the physical and chemical pathways taken by the biogenic elements and compounds from their origins in stars to their incorporation into planetesimals.
>
> The observed circumstellar dust and molecules indicate that nucleation and growth of carbonaceous particles occurs in the envelopes of carbon stars. Similar processes are thought to occur under diverse conditions ranging from those in interstellar clouds to those in the atmospheres of the outer planets and their satellites. In both types of environments, observational evidence suggests the presence of fine-grained dust 0.1 to 1 μm in diameter, presumably containing varying proportions of hydrogen, carbon, nitrogen, and oxygen. Based on remote spectrophotometric observations, some properties of cosmic dust have been postulated, yet the physical and chemical characteristics of the material and the nature of the processes that produce it remain poorly understood and almost entirely in the realm of theory.

Although theories of grain nucleation and dust growth are being developed, the complexity of these processes make them difficult to model. The few experimental studies that have been conducted were performed under conditions that do not permit scaling to relevant astrophysical environments. In such environments, one feature common to the processes mentioned above is the formation and evolution of grains over substantial lengths of time while being suspended in a thin gas phase largely, if not entirely, independent of other grains. This condition should influence the rate of formation, chemistry, structure, morphology, and other characteristics of the dust. While this condition is difficult, if not impossible, to model in a terrestrial laboratory, it may be effectively simulated in microgravity. Experiments in Earth orbit would provide "space truth" for analogous experiments carried out in terrestrial laboratories and on computers. Furthermore, they would yield, under well-defined conditions, samples whose properties could readily be determined and compared with those of natural material either remotely sensed or obtained from meteorites, interplanetary dust, or comets.

A dust grain can grow by the passive accretion of gaseous species to its surface; it can also provide an active surface to catalyze reactions of species sorbed to it or can be changed by chemical reactions with sorbed gases. Chemical reactions between gas and dust hypothesized to occur in interstellar clouds and in the solar nebula may account for organic matter observed by radio astronomers in interstellar clouds and by chemists in meteorites, comets, and interplanetary dust. Grains are of further interest as grain accretion is responsible for the formation of planetesimal-sized objects from small grains in the solar nebula. Other hypothetical gas-grain processes of nebular or interstellar relevance that merit study include the hydration of silicate grains to phyllosilicates by gaseous water, the photo-irradiation of icy mantles of grains by starlight, and the thermal evolution of interstellar condensates in the solar nebula. The microgravity environment of the GGSF would provide excellent opportunities for model studies of these processes. [3]

2.1.3 Biology and Exobiology Comments and Findings

Although the GGSF will be an important tool in aerobiology, this field seems to be under-represented in the list of strawman experiments. Many important biological questions that could be explored in microgravity should be added to the science objectives. Perhaps the most important question concerns the possible effects of biologically active aerosols in the closed microgravity environment of a space craft, for example, Space Station Freedom.

Aerobiology experiments on GGSF must be preceded by Earth-based experiments that will provide data separating aerosol effects from microgravity effects. Microgravity effects, such as the removal of geotaxis (the response of a freely moving organism to gravity), will be present in the GGSF but not in aerobiological systems in the Earth's atmosphere. Comparing GGSF studies with Earth-based aerobiology research (employing electrostatic levitation or a rotating drum experiment chamber) will help to differentiate aerosol effects from microgravity effects.

Exobiology research on GGSF should include studies of atmospheric processes (e.g., photolysis from the gas phase and photochemistry on particulates), cometary processes, radical reactions occurring on dust grains, and polymerization reactions. Although radical reactions on dust grains at low temperatures (less than 40 K) are of considerable interest, there are no strawman experiments relating to this topic from which requirements can be derived. Similarly, microgravity experiments investigating cometary processes are not represented in the strawman experiments.

Although adequate for most of the strawman experiments, the 67 liter chamber proposed in the concept design may be too large for certain exobiology experiments in microgravity. For example, a volume of approximately 4 liters would be more reasonable for experiments involving UV photolysis.

Additionally, since the wavelength and intensity of photolyzing radiation may be important experimental parameters, the ability to select among a variety of wavelengths and intensities should be included in the facility design.

2.2 PLANETARY SCIENCE

2.2.1 GGSF Science Goals in Planetary Science

Planetary Science is the study of the cosmological processes that led to the formation of the Solar System and the study of the behavior of geological and atmospheric materials on evolved planetary bodies. Several aspects of the formation of the Solar System and the subsequent behavior of materials in the atmospheres of evolved planetary bodies are appropriate for research utilizing the Gas-Grain Simulation Facility.

> ...Research interest centers around the behavior and the interaction of particulate materials that have paths distant and free from the influence of a solid or liquid surface. The particles of interest range from centimeter size particles of ice and dust to submicron comminution products and condensates. Some of the most fundamental processes involved in the origin and evolution of the Solar System concern the condensation of solid matter from a gas, the aggregation of small particles to form large particles, and the collisional interaction of particles.
>
> Understanding particle condensation is critical to understanding the earliest stages of Solar System formation. Classical nucleation theory cannot adequately predict the condensation of protoplanetary particles from the early solar nebula. Experiments have been performed in terrestrial laboratories to simulate this process, but such experiments often suffer from convective instabilities induced in the gas from which the condensation takes place. In a microgravity environment, it will be possible to conduct condensation experiments with more refractory materials. Experiments extended to low-temperature condensation will also be able to investigate the formation of the icy grains that accreted into the outer planets, their satellites, and comets.
>
> Once grains formed by condensation in the early solar nebula, they underwent aggregation into planetesimals. The Solar System, in its nebular state, began as particulate material that interacted at low relative velocities to form larger aggregates of material and, ultimately, the planetary bodies. Immediately after the first stages of particle aggregation in the solar nebula, planetesimal formation probably involved collisions of particles at relative velocities of a few meters per second or less. The detailed dynamics of such collisions, in particular the nature of the conditions necessary for particles to adhere together after a collision, are poorly understood. The effects of factors such as particle composition, relative sizes, spin, and ambient gas pressure on collision dynamics are not well known.
>
> Within the evolved planetary system, particles of ice and dust form an unconsolidated component of some planetary bodies in the form of ring structures such as those of Jupiter, Saturn, and Uranus. Again, interest lies in understanding

low energy collisions of such particles since this process determines the structure and behavior of ring systems. The particles of interest here are more coherent solids than the ice/dust aggregations mentioned above. Collisions result in an effective viscosity for the rings and in development of diffusional instabilities that are manifested as intricate small-scale structures. In this case the most important parameter to understand is the coefficient of restitution which describes the inelasticity of collisions. Attempts have been made to study low velocity particle collisions by suspending particles from pendulums, but such experiments suffer severely from the restriction of particle motions. However, full three-dimensional interactions, including spinning particles and the interaction of more than two particles, can be conducted in a microgravity environment. The evolution of the planetary ring systems may also have been dependent on the interaction of electrostatically charged micron to sub-micron size dust particles that interact electrically with an ambient plasma. The behavior of such particles also has direct relevance to understanding comets that emit dust at large heliocentric distances. [4]

After reaching certain sizes depending on location in the solar nebula, primarily the distance from the sun, the planetesimals mentioned above will begin to acquire atmospheres. Depending on the object's size and effective temperature, these atmospheres will be retained and will chemically and physically evolve after the accretion process has ended. In fact, all of the planets in the outer solar system possess atmospheres as do the largest satellites Titan and Triton. More importantly, all of these atmospheres contain aerosols, which are primarily the products of chemistry of the gases present at the end of planetary formation. At present, little is known about these aerosols except for some constraints on their optical properties and sizes imposed by spectral observations. How the aerosols were formed and how they grow, aggregate, and settle in the atmosphere is not well understood. Since the presence of aerosols can have profound effects on the physical, chemical, and thermal properties of atmospheres, study of particles in planetary atmospheres is important in understanding how atmospheric properties are affected by aerosols, and in elucidating how the atmospheres evolved to their present states. Information about the latter would also be helpful in understanding the conditions required for development of atmospheric environments suitable for life.

Interacting particles are also found within the atmospheres of the terrestrial planets. Such materials range from grains less than a micron to several tens of microns in size and owe their presence in suspension to the action of aeolian, volcanic, and impact processes. Particle aggregation caused by the electrostatic interaction of these atmospheric particulates may strongly influence the life-span of dust storms, the behavior of volcanic eruption plumes, and the potentially global effects (such as species extinction) of impact dust palls. For example, it has been hypothesized that a large meteorite or comet impact could have caused substantial atmospheric dust loading on Earth and subsequent faunal (e.g., dinosaur) extinctions. Such hypotheses are dependent on the rate of dust aggregation and the rate at which particle aggregates settle from the atmosphere....

All aggregation experiments are severely restricted in duration by rapid settling in a 1 g gravitational field. The microgravity environment on the Space Station will allow the process of particle aggregation to be studied in great detail under a wide range of conditions. A sample of specific parameters that need investigation includes aggregation rates, the size distribution of aggregates, and the dependence of aggregation efficiency on material properties. [5]

2.2.2 Planetary Science Comments and Findings

The current GGSF strawman experiments adequately cover the range of planetary science experiments appropriate for the Facility. Other research interests in planetary science that might benefit from microgravity experimentation (e.g., simulations of the lower atmospheres of the outer planets, simulations of the atmospheres of the inner planets, simulations of high-speed micrometeorites and cratering) would require experiment capabilities far beyond those currently planned for the GGSF (e.g., extreme temperatures and pressures, toxic and corrosive atmospheres, and very high velocities), and should not presently be considered as good candidates for GGSF experiments.

Several issues that are important to planetary science research are not properly addressed in the conceptual design. The most important issue involves maintaining cleanliness in the experiment chamber and on the viewing port windows. Another critical issue concerns the material of which the chamber walls are constructed: conductive materials such as Ni, Fe, and Cu are noted catalysts for chemistry and could cause problems in some of the strawman experiments (e.g., tholin formation); non-conductive coatings may influence experiments through uncontrolled surface charges. Experiment-specific hardware and mounting points inside the experiment chamber will also influence the experiment through altered fluid flows and possible static charges. These chamber and environment issues are discussed further in Chapter 4.

The magnitude and orientation of the acceleration vector within the experiment chamber will have a strong influence on the outcome of some experiments, especially those involving low-velocity particle motion such as the low-velocity collision experiments. For these experiments especially, measurements of the local acceleration levels will be necessary.

2.3 ATMOSPHERIC SCIENCES

2.3.1 GGSF Science Goals in Atmospheric Sciences

Topics that are currently of major interest in atmospheric sciences include cloud droplet and ice particle nucleation, growth, and interactions; aerosol particle coagulation and agglomeration; heterogeneous chemistry; and the effects of all these processes on the optical properties of aerosol particles with and without the presence of water. Investigation of these topics is important for improving our understanding of precipitation processes, long-range transport of pollutants, atmospheric chemistry including ozone depletion, visibility and air quality, and the Earth's radiation balance in the context of global warming or cooling (nuclear winter) hypotheses.

A low-gravity environment offers opportunities to investigate specific mechanisms or processes under controlled conditions over long time periods and in the absence of convective fluid motions. Cloud droplet and ice crystal nucleation and growth can be observed with minimal interferences due to sedimentation and convection. Particle interactions including coagulation, ice particle aggregation, and the scavenging of aerosol particles by cloud droplets or ice crystals can be simulated over a wide range of time scales inaccessible at terrestrial gravity levels. Slow heterogeneous chemical reactions, such as those which occur in aqueous droplets or on the surfaces of ice crystals, can also be studied. The reflectivity of incoming solar radiation by non-freezing terrestrial clouds is strongly influenced by the size distribution of the cloud droplets; this represents one of the major unknowns in global climate modeling. Also of importance to models is that the optical properties of water ice clouds are uncertain in both the visible and infrared regions of the spectrum. The properties of carbonaceous particles with and without the presence of water are a current research area for many of the same reasons. Carbonaceous particles are widely distributed in the terrestrial atmosphere, sometimes in concentrations sufficient to cause significant surface cooling (e.g., beneath Kuwait oil smoke layers). The possibility of modeling the optical properties of carbonaceous agglomerates using fractal concepts is being investigated. Water condensation onto carbonaceous agglomerates may significantly alter their mechanical and optical characteristics. These properties of water and ice cloud particles can be investigated in low-gravity chambers where the particles can be generated and subjected to a wide spectral range of optical measurements.

One of the science goals of the GGSF is to provide an opportunity to investigate these and related atmospheric sciences topics and hypotheses in a microgravity facility which permits elimination of gravity-related physical variables in complex processes, allowing vital observations which could not be obtained in any other way.

2.3.2 Atmospheric Sciences Comments and Findings

There is a wide variety of potential GGSF experiments which would benefit research in the atmospheric sciences. Though this field is fairly well represented in the GGSF strawman experiments, more could easily be added. Several of the Atmospheric Cloud Physics Laboratory (ACPL) experiments are still important and may be appropriate (in a slightly modified form) for the GGSF. Other new GGSF experiment topics which could be developed into strawman experiments include the following: droplet formation on heterogeneous aerosols of soluble and insoluble condensation nuclei; diffusion-driven aggregation (perhaps with "monodisperse" polystyrene spheres); effects of microgravity on respiration of particle-laden air (e.g., smoke and soot from an electrical fire on SSF); sulfate conversion on soot in water clouds (i.e., acid rain formation); and dispersion experiments (e.g., flow patterns and propagation of vortices in the absence of buoyancy).

Water droplets or ice particles are important objects of study in the atmospheric sciences. The ACPL project (see Chapter 1) should be carefully reviewed with an eye towards including aspects of its design in the GGSF design. For example, a diffusion chamber or an expansion chamber similar to those planned for the ACPL will probably be needed for any microgravity atmospheric cloud experiment. Also important are monitoring and controlling the water content of the gas in the experiment chamber; some experiments may require only coarse control of the relative humidity while others will require closely controlled supersaturation levels.

Aerosol generation techniques must also be considered for the GGSF design. In terrestrial laboratories, an aerosol particle distribution is often "sized" and "shaped" to give better control over the experiment's initial conditions. This may be appropriate for GGSF experiments as well. Generation of particles in microgravity, as opposed to terrestrial conditions, may affect initial particle properties including concentration, size, morphology, and chemistry; apart from experiment design considerations, this may be a research issue. Perhaps more important than being able to control the experiment conditions is being able to measure those conditions. An example of this is the acceleration level which, although it cannot be controlled, is an important parameter which must be measured accurately in order to understand experiment results.

To increase science return, the GGSF project should ensure that GGSF experiment development includes an exploration of variations in parameter space so that experiment success or failure is not linked too closely to the performance of untested hardware. This preparatory research for GGSF experiments should also include a modeling of the effects of different acceleration levels and of accelerations that change over time.

2.4 ASTROPHYSICS, CHEMISTRY, AND PHYSICS

2.4.1 GGSF Science Goals in Astrophysics, Chemistry and Physics

From the detailed discussion of science goals in the report of the 1987 GGSF science workshop, the following describes the GGSF science goals in the field of astrophysics:

> Astrophysics is the study of matter and energy in the universe. As such, it is concerned with the formation, life cycle, and death of stars, as well as with processes that occur in the interstellar medium. Small grains play an important role in several stages of stellar evolution. In protostars, the infrared opacity of the accretion disk is controlled by the properties of grains; size distribution, composition, degree of aggregation, volatile content, and other parameters all play important roles in determining the properties of the protostar. The efficiency with which grains coagulate into larger aggregates will determine the size of the objects that remain in orbit after the T-Tauri phase has swept away the excess gas of the accretion disk and will therefore determine the probability of planet formation. As stars near the end of the hydrogen-burning phase, atmospheric pulsations might eject matter high into the stellar atmosphere. If such matter contains a sufficient concentration of refractory vapor, it will nucleate into small grains that can be pushed away from the star by radiation pressure. These grains tend to drag the surrounding gas away with them and can set up conditions in which a steady rate of mass loss is established. Such mass loss eventually leads to extensive shells (planetary nebulae) surrounding old stars: here too, grains play a significant role in scattering light from the central star throughout the nebula.
>
> When the material produced in circumstellar outflows mixes with that in the general interstellar medium, a variety of gas/grain interactions might occur. Such interactions include chemical sputtering, hydration, oxidation, reduction, adsorption, surface catalysis, and the formation of grain mantles. Each of these processes will affect both the surface properties of the grains as well as the chemical composition of the interstellar gas. Other processes such as annealing, cosmic-ray bombardment, grain coagulation or grain-grain collisions will only affect properties of the grains. Even though many aspects of the above processes can be studied in terrestrial laboratories, several crucial measurements can be made only in a microgravity environment. Examples of such measurements include the coagulation efficiency and final morphology of a variety of refractory grains, the strength of the aggregates, both with and without ice mantles, and the optical properties of "fractal" aggregates of dielectric particles, of metal grains, and of mixtures of the two.
>
> Astrophysicists will use the microgravity environment of the Space Station to measure the formation rate, optical properties, and intrinsic strength of particle aggregates that would collapse under their own weight in a terrestrial laboratory. Such aggregates may also play key roles in the transport of condensible species and specific isotopic anomalies from circumstellar environments into primitive stars (in particular, the protostellar nebula). However, before models of such transport mechanisms are constructed, measurements of the formation and destruction rates of the aggregates must be performed. Similarly, if we are to test theories that predict the abundance patterns of such aggregates throughout the galaxy, then some means of detecting them must be found. Experimental studies in the Gas-Grain Simulation Facility aboard the Space Station will play a central role in our quest for understanding these phenomena. [6]

Physics and chemistry comprise what is often referred to as "basic science", that is, science upon which other scientific disciplines are based. A microgravity research environment enables a variety of "basic science" investigations that are intrinsically of interest, but may have an impact on other science disciplines as well. The following examples illustrate the range of basic science investigations envisioned for the GGSF:

- Study the transition from atomic/molecular behavior to bulk material behavior in bimetallic molecular aggregates. This will aid in understanding the role of geometry and composition in the properties of bulk alloys.

- Investigate the interaction of colliding crystals as they approach and make contact. This is important in the growth of grains in planetary atmospheres and the collisional disruption or coalescence of particles in the interstellar medium.

- Study the effects of convection on coagulation and wall deposition on aerosols of micron and larger sized particles. The effects of diffusion in the absence of buoyant convection must also be studied and applied to all microgravity experiments.

- Study the formation and optical properties of organic aerosols.

2.4.2 Astrophysics, Chemistry, and Physics Comments and Findings

A number of additional studies in astrophysics, physics, and chemistry could be considered appropriate for the GGSF but are not represented on the list of GGSF strawman experiments. These include studies of fullerenes, metal cluster growth, chondrule formation, water percolation in planetesimals, micro-encapsulation of pharmaceuticals, and gas-grain catalysis (e.g., in chemical engineering).

These and any other experiments suggested for the GGSF should be scrutinized to ensure not only that microgravity is truly required, but also that another microgravity facility might not be more suitable.

There are important technical capabilities required for much of this research that have not been fully addressed in the conceptual design. Most important of these are chamber, window and detector contamination and cleaning, which are critical for all science disciplines if more than one experimental run is to be performed in the same experiment chamber. This is discussed further in section 4.1. Experiments in which chemistry is important will require high-purity gases—the 99.5% N_2 planned for Space Station Freedom will not be pure enough in many cases. Temperature and pressure limits might also be re-examined. Temperatures lower than 40 K would considerably expand the Facility's science capabilities, and may be attainable in a smaller experiment chamber. If the experiment chamber is sufficiently small, pressures lower than a microbar may be attained which may be important for single grain experiments, although they may not be attainable in experiments involving dispersion or generation of grains and grain assemblies.

CHAPTER 3

GGSF EXPERIMENT MATERIALS

This chapter examines the materials required by the GGSF strawman experiments. The categories of Dispersed Solids, Dispersed Liquids, High-temperature Materials, and Ambient/low-temperature Materials correspond to four discussion sessions at the 1992 GGSF Science Workshop. Scientific significance, strawman technical requirements and workshop comments and findings are presented for each material category.

3.1 DISPERSED SOLIDS

This section focuses on solid particles formed by the deagglomeration and dispersion of previously subdivided material. Solid particles formed by other processes, such as condensation from supersaturated vapors or freezing, will be discussed in other sections. Particles in this category are composed of mixed mineral compounds as well as single compounds (e.g., silicate) and single elements (e.g., carbon). Manufactured microspheres with controlled morphology and sizes are included. Particle morphologies range from spherical to angular fragments with aspect ratios between about one and four. Particle sizes range from 0.05 μm to 1 mm.

3.1.1 Scientific Significance

The ability to disperse a cloud of solid particulates in low-gravity will allow simulation and study of processes and phenomena which involve, for example, naturally occurring mineral material found in planetary atmospheric dusts, interplanetary and interstellar dust particles including carbon and silicates, and planetary atmospheric particulate material such as sulphur which may serve as nuclei for the formation of various ices. The coagulation rates (kernels) for solid particles of irregular morphologies such as geological dusts are not well known. The morphologies of the aggregates formed by the coagulation of these particles are also not well known but affect the optical properties of the aggregates and hence their role in problems such as evaluating radiative transfer in planetary atmospheres. Suggested GGSF experiments to study such phenomena would utilize a variety of dispersed geological materials (basalt, quartz, etc.). Interplanetary particles such as micrometeorites are of interest for reasons that include their spectroscopic properties, and as sources of fragments following radiation-induced breakup. Particles previously captured from high altitude or orbiting craft (e.g. Brownlee particles) would be utilized in some experiments. Manufactured microspheres of controlled dimensions are of interest for investigations of particle transport and deposition in gaseous media. Table 3.1–1 summarizes some of the scientific motivations for research involving these types of materials.

Table 3.1–1. Scientific Significance of Dispersed Solids

Particle Type	Scientific Significance
Mineral material	Aggregation and formation of solid bodies; climatic impacts of dust on terrestrial or planetary atmospheres; polarization and scattering of light; emission spectroscopy; rotation induced by light pressure
Freezing nuclei	Crystalline growth rates and morphologies for ices of ammonia, methane, carbon dioxide, water
Manufactured microspheres	Particle coagulation and deposition processes in convective flows
Micrometeorites, surrogates of interplanetary, interstellar, circumterrestrial particles	Infrared emission spectra; radiation-induced rotation and bursting

3.1.2 Technical Requirements

The technical requirements for the generation of solid particles from previously subdivided material include particle sizes and concentrations, and the pressure and temperature ranges of the corresponding experiments. Unless otherwise noted, size specifications given are for single particles as described in the experiment initial conditions, although particle coagulation will, in many cases, rapidly produce multiple-particle aggregates. The technical requirements for GGSF strawman experiments [10] are summarized in Table 3.1–2.

Table 3.1–2. Technical Requirements for Dispersed Solids

Particle Composition	Size Range [μm]	Concentration [number/cm^3]	Pressure [bar]	Temperature [K]
Silicate aggregates	10^3 to 10^4	(2 particles per experiment)	10^{-6} to 10^{-3}	150 to 500
Basalt, quartz, pyroclastic material	0.1 to 10^3	10^8	10^{-3} to 1	221 to 366
Sulphur, phosphorus	0.1	10	0.03 to 3	80 to 300
Silicate; carbon (amorphous, graphite)	0.05 to 10^3	1 to 10^{10}	10^{-9} to 10^{-8}	10 to 300
Glass, silicon, polymer microspheres	1 to 20	10 to 10^5	1	243 to 373
Micrometeorites, surrogates of interplanetary particles	<1 to 10^3	(2 to 20 particles per experiment)	10^{-12} to 10^{-9}	4 to 1000

3.1.3 Workshop Comments and Findings

Several points need to be considered concerning experiment requirements as expressed by the GGSF strawman experiments, and the concept design responses to them; particle generation, dispersion in experiment chambers, and chamber cleaning issues are included.

The main findings concerning experiment requirements pertinent to dispersed solids are as follows:

- The ranges of particle size are often specified in general terms in the strawman experiment descriptions, but requirements for the initial experiment conditions have not been distinguished from the evolution of size spectrum during the experiment. Size distribution parameters and monodispersity or polydispersity need to be clarified.

- In some experiments, establishing and maintaining desired electric charge levels on particles may be critical to the phenomenon being investigated. Appropriate methods are yet to be determined. In other cases, particle charge may be an unwanted side-effect of particle dispersion which complicates the experiment: it affects deagglomeration, aggregation and other physical phenomena. A common method of neutralizing particle charge is with krypton 85; but, is a radioactive gas or solid a safety concern? Another method to neutralize charge is by corona discharge; but, is the associated high voltage a problem? This subject requires further study.

In examining GGSF design issues, technical ideas which should be considered in the areas of generation, dispersion, and chamber cleaning include the following:

- Particle generation and size distribution shaping techniques are size dependent. These techniques only work over limited size ranges with little or no overlap. Previously subdivided and sized material can be used if deagglomeration is efficient, but presently available deagglomeration methods (fluidized bed, gas jet, and other techniques) have been shown to work only for particles larger than about 1 µm.

- There has been some success with enhancing the deagglomeration process by cooling the bulk samples to liquid nitrogen temperatures.

- Dispersion may also be possible by containing large particles in an inflatable bladder or bellows. The mechanical action of inflation might re-suspend the particles, then electrostatic positioning could be applied to create a spatially uniform distribution.

- More work needs to be done in order to clarify when it is acceptable to use a carrier gas to introduce sample materials into an experiment chamber and when it is not. A carrier gas may be necessary in order to deagglomerate and disperse particles but may be incompatible with a requirement for very low experiment gas pressure.

- Chamber cleaning is a generic requirement which often needs careful interpretation. For example, the accumulation of particles on chamber walls may not be objectionable nor constitute contamination as long as it does not interfere with diagnostics. But, in an experiment requiring vacuum, such accumulations might contribute significant vapor pressures of contaminating compounds. This issue is discussed further in section 4.1.

- More effort should be focussed on taking advantage of existing published laboratory techniques in the areas of particle generation, dispersion, and chamber cleaning.

3.2 DISPERSED LIQUIDS

This section addresses aerosol particles consisting of liquid droplets formed by the atomization of bulk solutions. Several of the GGSF strawman experiments require dispersed liquids, including aqueous solutions of common inorganic salts and of complex organic compounds. Aqueous suspension droplets containing microbes are included. Semi-liquid particles consisting of nitrogen and hydrocarbon reaction products are also of interest but would be generated *in situ* by photochemical or other reactions which are themselves the focus of some experiments. Dispersed liquid particles are required in sizes ranging from 0.1 μm to 3 mm, and in varying concentrations as indicated in section 3.2.2.

3.2.1 Scientific Significance

Dispersed liquid particles either singly or in ensembles (clouds) are of interest to terrestrial atmospheric, biochemical, and basic physical and chemical studies. Aqueous droplets provide environments for chemical and biological processes and hence are of interest in the study of prebiotic chemical evolution. Aqueous droplet growth rates and coagulation processes determine terrestrial warm cloud microstructure and optical properties such as albedo. Ice crystal morphologies and compositions are modified by the collection of aqueous droplets during scavenging processes. Table 3.2–1 summarizes some of the motivations for research involving dispersed liquids.

Table 3.2–1. Scientific Significance of Dispersed Liquids

Particle Type	Scientific Significance
Pure water or dilute inorganic aqueous solutions	Coagulation and wall deposition in convective flow; droplet growth rates; droplet scavenging by ice crystals
Aqueous solutions of amino acids or antifreeze glycoproteins	Polymerization of amino acids in droplets through cycles of evaporation and re-condensation; structural studies of antifreeze glycoprotein crystals from saturated solution droplets
Aqueous suspensions of microbes	Viability of airborne bacteria in various gaseous environments

3.2.2 Technical Requirements

The technical requirements for the generation of dispersed liquid particles include specifications on particle sizes and concentrations, and the pressure and temperature ranges of the corresponding experiments. The size specifications are anticipated values covering the ranges expected for the experiments; however, it should be noted that liquid particles are exposed to supersaturations of their vapor phases in some of the strawman experiments; these will experience continuous growth toward the stated upper size limits. Table 3.2–2 gives the technical requirements for the generation of dispersed liquids for the GGSF strawman experiments [10].

Table 3.2–2. Technical Requirements for Dispersed Liquids

Particle Composition	Size Range [μm]	Concentration* [number/cm^3]	Pressure [bar]	Temperature [K]
Aqueous NaCl solution	1 to 100	1 to 10^3	0.1 to 1.0	273 to 303
Aqueous amino acid solution	0.1 to 0.2	10^6 to 10^7	0.05 to 1.0	203 to 353
Saturated aqueous solution of antifreeze glycoprotein	10^3 to 3×10^3	1.5×10^{-5}	1	277 to 293
Pure water	1 to 2×10^3	1 to 10^5	10^{-4} to 1.2	233 to 373
Aqueous suspension of bacteria	0.5 to 2.0	10^3 to 10^5	1	278 to 313

* **Based on a 67 liter chamber in GGSF Phase A concept design.**

3.2.3 Workshop Comments and Findings

The main findings concerning the experiment requirements for dispersed liquids are as follows:

- The strawman experiment descriptions often do not specify the required liquid particle initial size distribution parameters; distribution width specifications are generally missing. Monodispersity is sometimes required, but is not defined nor quantified.

- Implicit to most experiments is a requirement for uniform dispersion following the generation of aerosol particles in the experiment chamber. More work is required in order to quantify this requirement.

The main findings, concerns, and suggestions regarding GGSF concept design issues are as follows:

- Both injector-type generators, atomizers and other techniques using carrier gas may fail to provide uniform dispersions, for example, because of the velocities they impart to the particles. Controlled flushing of the chamber with an aerosol works in terrestrial laboratories and was considered for the Atmospheric Cloud Physics Laboratory. These and other techniques should be studied for their potential application in the GGSF design.

- Aqueous particles could be generated in an ancillary device such as a diffusion cloud chamber by condensation of water onto selected nuclei.

- A potential monodisperse droplet generation method, electrostatic dispersion, is in use in some laboratories, and should be investigated.

3.3 HIGH-TEMPERATURE SAMPLE MATERIALS

High-temperature aerosol particle formation processes are one form of familiar evaporation-recondensation procedures for the formation of particles from initially supersaturated vapors. In this category, materials of relevance to potential GGSF studies include carbon soots formed in the combustion of various hydrocarbon fuels, metallic or silicon oxides formed by heating those elements in the presence of oxygen, and metallic particles formed by heating in inert atmospheres. The particles are assumed to form by homogeneous nucleation, that is, without previously-existing nuclei or substrates on which to condense. Initial particle dimensions are typically on the order of tens of nanometers. Particle dimensions stated here refer to the individual spherules which commonly form in condensing vapors, although aggregation and chaining of those spherules usually proceeds rapidly.

3.3.1 Scientific Significance

Particles in this category are of interest for use in studies of phenomena which include interstellar dust aggregate formation and optical properties; liquid water and water ice particle nucleation and growth; the formation of bulk metallic properties including absorption spectra; and the optical properties of carbon soot and unpyrolyzed organic carbon compound aggregates. Interstellar dust is thought to include carbon and silicate compounds which condense in cooling stellar atmospheres. These particles may be found in an unmixed state or may serve as nuclei for the condensation of additional material such as metallic compounds. In the terrestrial atmosphere, soot and other materials such as silver iodide may serve as liquid water or water ice nuclei. Complex organic carbon compounds such as polycyclic aromatic hydrocarbons (PAH) may be formed in the carbon-rich atmospheres of highly evolved stars; PAH compounds may explain some features of visible and ultraviolet starlight absorption spectra. Table 3.3–1 provides further elaboration on the scientific motivations for research involving particles formed by high-temperature evaporation followed by condensation.

Table 3.3–1. Scientific Significance of High-temperature Materials

Particle Type	Scientific Significance
Carbonaceous soots	Optical properties of aggregates; climatic impact of smoke; liquid water and water ice nucleation
Metals, bimetals	Circumstellar and interstellar dust particle formation, coagulation, light scattering and extinction; transition from atomic/molecular optical properties to bulk metallic properties
Metal and silicon oxides	Simulation of interstellar dust cores on which other metallic compounds condense or ices form, creating mixed-particle aggregates
Ice nuclei (AgI for water ice)	Formation of ice crystals of varying morphologies for optical/radiation studies; Earth's radiation balance
Polycyclic aromatic hydrocarbons (PAH)	Evaluation of optical properties, spectroscopy of PAH aggregates

3.3.2 Technical Requirements

The technical requirements for the generation of particles from materials exposed to high-temperature processes include specifications on particle sizes and concentrations, and the pressure and temperature ranges of the corresponding experiments. Unless otherwise noted, size specifications are stated in terms of single particles, corresponding to experiment initial conditions, although particle coagulation will in many cases rapidly produce aggregates composed of multiple particles. The technical requirements for this sample particle category, for the GGSF strawman experiments [10], are summarized in Table 3.2–2.

Table 3.3–2. Technical Requirements for High-temperature Materials

Particle Composition	Size Range [μm]	Concentration [number/cm^3]	Pressure [bar]	Temperature [K]
Carbonaceous soot	0.03 to 1	1 to 10^8	10^{-4} to 1.2	233 to 303
Metals, bimetals	0.02 to 100*	10^8 to 10^{11}	1	77 to 296
Metal and silicon oxides (MgO, CaO, Al_2O_3, SiO)	0.01 to 0.1	10^4 to 10^{11}	10^{-6} to 1	77 to 300**
Ice nuclei (AgI)	~ 0.1	1000	10^{-4} to 1.2	233 to 293
Polycyclic aromatic hydrocarbons	5×10^{-4} to 0.01	1 to 10^{10}	10^{-9} to 10^{-8}	10 to 300***

* Upper end of size range specification is the expected size of aggregates formed during experiment rather than a prescribed initial condition. ** One proposed experiment would utilize temperatures up to 1200 K. *** Temperatures up to 1000 K may be desirable for other experiments that are not yet reflected in the GGSF strawman experiment set.

3.3.3 Workshop Comments and Findings

The findings concerning high-temperature sample generation address both the GGSF experiment requirements and the concept design. The main points concerning the GGSF strawman experiment requirements are as follows:

- The initial conditions describing the state of the aerosol at the beginning of an experiment are defined in terms of the fully and uniformly dispersed aerosol in the experiment chamber. However, these requirements should also include specifications for the state of the aerosol (particles and gases) at the exit plane of the generator, thus separating the generation and dispersion requirements and providing generator output parameters which should be monitored.

- Requirements need to be specified for the post-experiment integrity and environmental control of particle samples stored for later return to terrestrial laboratories.

Comments and concerns pertaining to the GGSF concept design are as follows:

- The design provision that particle generators be modular units with standard chamber interfacing is good. Monitoring of critical parameters (e.g., pressure and temperature) is also necessary. These parameters and generator bulk sample supply requirements could be quantified in ground-based or KC–135 tests.

- High-temperature generators such as crucibles may cause heat transfer to the experiment chamber and perturb its thermal stabilization. Additionally, the presence of high temperatures and thermal gradients may increase particle cohesion and diffusion which would increase the difficulties of dispersing and positioning the generated particles. Such issues should be considered carefully in the design of GGSF high-temperature generators.

- Existing containerless evaporation technology should be reviewed to assess its potential relevance to the GGSF design requirements.

3.4 AMBIENT/LOW-TEMPERATURE SAMPLE MATERIALS

The discussion in this section will focus on two types of particles: those formed at temperatures low enough to form the solid phase (ices) of compounds including water, carbon dioxide, ammonia and methane; and those formed at low-to-ambient temperatures by the irradiation of hydrocarbon and nitrogen gas mixtures. This discussion includes pure ice crystals of varying morphologies (habits), ice crystals formed on nuclei composed of other compounds, thin ice or frost layers formed on the surfaces of relatively large ice spheres composed of the same or a different compound, and small organic carbon particles and aggregates. The desired sizes of the particles vary from submicron to centimeter scales, and can only be specified as anticipated values in the context of experiment conditions which often promote continued growth.

3.4.1 Scientific Significance

Ice particles or coatings of various ices on substrate particles are of relevance to a wide range of scientific investigations within disciplines ranging from terrestrial and planetary atmospheric physics to planetary and interstellar science. The optical properties (absorption and scattering) of ice crystals determine their roles in radiative transfer calculations, hence their importance to climate models or to determining spectral features of planetary atmospheres. Ices of various compounds may form coatings on interstellar or interplanetary particles, altering their optical properties and mechanical behavior such as the coefficient of restitution in collisions, the conversion of linear to angular momentum, or the adhesion of particles. Hazes of complex organic heteropolymer particles ("tholins") formed by the irradiation of nitrogen and simple hydrocarbon gas mixtures are found in the atmospheres of Titan and some of the outer planets (Uranus, Neptune). The specific scientific motivations for the study of this material category in GGSF strawman experiments are summarized in Table 3.4–1.

3.4.2 Technical Requirements

The technical requirements for the generation of ices, ice coatings, and other solid particles from materials exposed to ambient-to-low-temperature processes include particle sizes and concentrations, and the pressure and temperature ranges of the corresponding experiments. Size specifications are stated either in terms of the expected ranges of ice crystal or other particle dimensions, or in terms of the net sizes of core particles with ice coatings. Large or complex particles may require preparation in an ancillary chamber, and a manipulation technique to introduce them into the experiment chamber. The technical requirements for ambient/low-temperature materials, for the GGSF strawman experiments [10], are summarized in Table 3.4–2.

Table 3.4–1. Scientific Significance of Ambient/Low-temperature Materials

Particle Type	Scientific Significance
Water ice crystals	Formation of aggregates and planetesimals; physics of coalescence of solids; diffusiophoretic and other scavenging mechanisms; scattering and absorption of visible and thermal IR radiation
H_2O, NH_3, CH_4, CO, CO_2 ice coatings on metal, silicate, or carbon particles	Formation of aggregates; coated aggregate absorption and emission spectra and scattering; radiative and dynamical characteristics of fractal materials which may have astrophysical significance
NH_3, CH_4, and CO_2 ice	Crystal growth habits, light scattering and absorption in atmospheres of outer planets
H_2O, NH_3, and CO_2 ice spheres with frost coatings	Linear and angular momentum exchange and energy loss of colliding particles in the formation of planetesimals and planetary rings; aggregation in low speed collisions
"Tholin" particles formed from reactions in N_2, CH_4, C_2H_2, and C_2H_4	Growth measurements and optical properties of particles in Titan's and other planetary atmospheres

Table 3.4–2. Technical Requirements for Ambient/Low-temperature Materials

Particle Composition	Size Range [μm]	Concentration [number/cm³]	Pressure [bar]	Temperature [K]
H_2O ice crystals	1 to 10^3	3×10^{-5}* (2 crystals) to 1	10^{-6} to 1.2	150 to 300
H_2O, NH_3, CH_4, CO, CO_2 ice coatings on metal, silicate, and carbon particles	0.02 to 1	3×10^{-5} to 10^{11}	10^{-9} to 1	10 to 296
NH_3, CH_4, CO_2 ice	0.1 to 100	40 to 4×10^7	0.03 to 3	80 to 300
H_2O, NH_3, CH_4, CO_2 ice spheres with frost coatings	~ 3×10^4	~3×10^{-5}* (2 crystals)	10^{-6} to 1	40 to 200
"Tholin" particles	0.01 to 1	~ 10^8	0.001 to 1	175 to 300

* Based on a 67 liter chamber in GGSF Phase A concept design.

3.4.3 Workshop Comments and Findings

The main findings, suggestions, and concerns pertaining to the GGSF concept design for ambient and low-temperature sample materials are summarized as follows:

- The direct measurement of single particle temperatures is a technology development issue. Temperature is measured indirectly by assuming thermal equilibrium of the particles with the surrounding gas and of the gas with the temperature sensor. The gas temperature could be measured more directly by monitoring the rotor levels of CO with low intensity IR laser irradiation. Thermal emission approaches should be investigated for determining the temperature of the particles themselves, independent of the gas. See Section 4.1.2 for additional comments on temperature measurement.

- Determining particle size distributions from optical scattering data is more difficult when the particles have irregular morphologies, as ice crystals do; the particle shape distorts any spectral signature. For such cases, alternative methods should be investigated.

- The restrictions on cryogenic fluids are a concern. Without cryogens, experiment temperatures are restricted to a lower limit of about 40 K. Lower temperatures are sometimes desired, for example, for IR detectors which operate at 4.2 K. Detectors which can work at higher temperatures should be investigated. Achieving temperatures as low as 6 K with state-of-the-art mechanical refrigerators may be possible. The 10 K to 15 K range is useful for studies of N_2, NH_3, CH_4, CO_2, and H_2O frosts.

- Temperature gradients along chamber walls and within experiment volumes must be minimized and controlled.

- The cleaning of chambers and connecting lines following an experiment is a concern, especially for the tholin experiments. If it is not possible to arrange experiment-dedicated chambers, disposable Mylar chamber liners may offer a solution. See Section 4.1.2 for additional comments on chamber cleaning.

- The requirements for particle generation and manipulation are varied and complex, and, in many cases, need further definition. Large ice particles may require a molding technique, while frosts may be formed by the expansion cooling of gases issuing from nozzles. It may be necessary to form particles in an ancillary chamber, then inject or position them in the main experiment chamber using a manipulation technique. Collision experiments will require both manipulation and a means of launching particles at the desired velocities.

CHAPTER 4

EXPERIMENT ENVIRONMENT AND DIAGNOSTICS

This chapter examines requirements for experiment environment and diagnostics, which are derived from the GGSF strawman experiments documented in the Experiment Information Database (EID). Environment and environment measurements, aerosol properties measurements, spectroscopic properties measurements, and geometric and kinematic properties measurements are each discussed in the following sections. Technical requirements for each measurement type and comments and findings of the 1992 GGSF Science Workshop are also presented.

4.1 ENVIRONMENT DIAGNOSTICS AND CONTROL

Environment diagnostics and control involve the monitoring of various experiment chamber environment parameters as well as, in some cases, their control. Environment parameters include gas temperature, pressure, composition, and humidity; gravity (acceleration, vibration), electromagnetic fields, illumination, and chamber cleanliness. Important environment parameters that are not monitored or controlled during the course of an experiment, but which constitute critical experiment requirements, are the chamber shape, dimensions, volume, and material properties.

4.1.1 Overview of Technical Requirements

This section outlines the environment requirements for the strawman experiments. The breadth of these requirements suggests the possibility that one chamber alone may not be sufficient to accommodate all the experiments. In fact, practical considerations may require that experimenters reconsider certain requirements in order to fit within the physical limitations of a feasible facility. The GGSF is constrained to occupy one International Standard Payload Rack (ISPR), which limits the size of a chamber which may be accommodated. Table 1.2–2 in Chapter 1 lists some of the ISPR features. The technical requirements presented here, however, were developed without full regard to such constraints since no conceptual design study had been performed when the requirements were formulated. The word "requirements" will be used here realizing that some are "desire—ments" unencumbered by potential practical constraints.

A distinction between active and passive control is made within this chapter and should be explained. If any environment property is provided in the chamber as an initial condition, but is not controlled thereafter, this will be referred to as passive control. If the property is controlled throughout the experiment, this will be referred to as active control.

The following discussion outlines experiment environment requirements; a brief summary is given in Table 4.1–1 as well:

Chamber

Requirements for chamber shape range from a sphere to a cylinder to a box; the minimum acceptable experiment volume requirements range from 0.1 to 100 liters (about 2/3 of strawman experiments need under 15 liters and only a few need more than 65 liters); material requirements are unspecified in most cases; and cleanliness requirements range from ultra-clean (dedicated chamber) to unspecified (most experiments). Additionally, ports for viewing, diagnostics, and sample generation and retrieval are needed; special materials such as quartz for UV transmission may be required for windows.

Temperature

Required temperatures range from 40 to 1200 K (3 strawman experiments listed 4 to 10 K desirable). Almost all experiments require temperature measurement (monitoring) and most need temperature control. The degree of control ranges from 0.001 to 25 K, but is typically in the 0.1 to 5 K range. Monitoring accuracy must be better than control accuracy by a factor of two or more.

Pressure

Requirements range from 10^{-12} to 3 bar (2 strawman experiments would benefit from pressures as high as 10 bar). The majority of experiments need active control. The required control accuracy varies widely. A stringent requirement at 1 bar is $\pm 10^{-4}$ bar and a requirement given at 10^{-9} to 10^{-8} bar is a factor of 2.

Gas Composition

Requirements call for gases and vapors such as air, N_2, He, Ar, O_2, Xe, H_2O, D_2O, CO_2, CO, NH_3, CH_4. Metal-bearing gases include CaO, FeO, MnO, K_2O, Na_2O. There are just two experiments which require active control. Active control would require a gas composition measurement instrument such as a gas chromatograph capable of monitoring to a greater accuracy than the required control accuracy. The aerobiological experiment, for example, requires 0.1 ppm control of NO and NO_2 at 0 to 5 ppm. The experiments requiring passive control need the initial gas mixture to be accurate within the range of 1 to 10%.

Humidity

Requirements range from dry to supersaturated. Several strawman experiments require active control with the most stringent being to 0.01%. Typically the requirement is 1 to 5%.

Other

Three strawman experiments require ultraviolet (UV) illumination for photolysis and one requires a radio frequency (RF) discharge for particle formation. Three experiments require electric fields (E-fields); two request gravity monitoring.

Table 4.1–1. Environment Requirements

Chamber Volume*	0.1 to 15 liters (a few experiments need 35 to 100 liters)
Temperature	40 to 1200 K (to 4 K desired)
Pressure	10^{-12} to 3 bar (10 bar desired)
Gas Composition	N_2, He, Ar, O_2, Xe, H_2O, CO, CO_2, NH_3, CH_4, etc.
Humidity	Dry to supersaturated
Other	E-fields & RF discharges (for particle formation), UV (for photolysis)

*minimum acceptable experiment volume

4.1.2 Workshop Comments & Findings

Chamber Cleanliness

One of the major issues to emerge from these discussion sessions is that of chamber cleanliness and the methods to achieve and maintain this cleanliness; chamber walls, windows, chamber parts and subsystem-to-chamber interfaces are of concern. This is an issue that is mentioned only occasionally in the experiment requirements. All requirements for cleanliness, however, do not have to be called out specifically. Some can be inferred from other requirements. For example, a need for low gas pressure already places requirements on chamber cleanliness to limit outgassing. Requirements on gas purity, sample purity, spectral transmission through windows and optical detector sensitivity also help to define the requirements on cleanliness of chamber surfaces and windows. In order to design the Facility with chamber cleanliness needs in mind, further quantitative definition by experimenters is required. Even with better definition, cleaning can be a difficult process to implement. The following suggestions for dealing with chamber cleanliness were made; these are possible candidates for future GGSF technical studies:

Chamber (general)

- Sequence experiments (e.g., from clean to dirty) to minimize the effects of contamination.
- Use a glove attachment port whereby an astronaut could manually clean the chamber or replace a window.
- Use a spray-on (e.g., latex) removable coating. However, the concern with removing a coating or bladder, or with opening the chamber for any reason, is that the integrity of seals would be compromised by opening and closing the chamber (particularly when a high vacuum must be achieved).
- Building multiple copies of each chamber design would allow a chamber to be replaced when it got dirty. All chamber cleaning could then occur on Earth.
- Place an inflatable "bladder" containing the sample into the chamber, creating a chamber within a chamber.

- Use non-stick walls (e.g., Teflon). For those cases where electrically conductive walls are required, electrically conductive Teflon may be used.

Windows

- Use a shutter system to keep windows clean. The volume enclosed between the shutter and the window could also be used to implement window cleaning via a purging cycle, a baking cycle, or some other method.

- Use a thin scrolling film that covers the window to provide a clean surface when needed (not good for UV since plastic films of this type tend to absorb these frequencies).

- Use a large rotatable window shield which will provide a new clean surface when it is turned.

- Equip windows with piezoelectric acoustic shakers. These can produce surface accelerations of over 10 g, which are capable of overcoming the van der Waals and electrostatic forces that cause particles to stick to the window.

- Ice formation on windows is an issue which needs further technical study.

- Spectral measurements can be calibrated to compensate for materials deposited on the window and the subsequent loss of optical transmission. This will only work up to a point as subtle spectral effects will be lost at low transmission.

Chamber Materials

Some materials proposed for the chamber (walls, interfaces, etc.) in the GGSF concept design such as Ni, Fe, and Cu are noted chemical catalysts and could be a problem for some experiments (e.g., tholin formation). Also, when a conductive chamber material is required to dissipate static charge, non-conductive coatings may quickly form (e.g., aluminum converts to aluminum oxide). Conductive coatings are also available and work well. Absorptive materials could pose a cleaning problem and should be avoided. The compatibility of chamber and device (sample generation, diagnostic, special equipment) materials must also be considered (more investigator input is needed). This leads to the following questions: Should the four proposed chambers be made out of different materials? Should several copies of each chamber be made, each out of a different material?

Chamber Temperature

The requirements on temperature include control accuracy which specifies the allowable point-to-point variations in the chamber. This raises the question of how long one can wait for equilibrium to be achieved since chamber wall, gas and particles all may be initially at different temperatures. It also raises the question of "the temperature of what" and how to measure it? Many methods of measuring temperatures are conceivable. In the case of monitoring a particle(s) in a vacuum, pyro-electric detectors may be employed (i.e., by using the thermal emission from the particle(s) as an indicator of its temperature). For low-temperature measurements, the population of rotor levels of CO could be used as a thermometer (i.e., by using a low intensity IR diode laser to monitor one population in vibration rotation transitions). Acoustic techniques could be used for those cases where pressure is high enough, and standard thermometers (thermistors, etc.) could be used on the inner walls of the chamber. Temperature should be measured all around the inner wall and in the interior of the chamber. Remote sensing is desirable, even if less accurate than other methods.

Chamber Pressure

If pressure control is required, it could be difficult to accommodate; thus its necessity should be well documented by the investigator making the request. Pressure gauges should be located as close as possible to the chamber—minimizing plumbing—in order to get an accurate reading. Redundant pressure measurements (three) are important, preferably with different technologies (two).

Chamber Gas Composition

Suggestions for monitoring gas composition include a flame ionization detector in a gas chromatograph and flame photometry. Two or more kinds of detectors would be desirable to measure the full spectrum of chemical components and to provide cross calibration.

Chamber Humidity

The GGSF concept design does not allow for active control of relative humidity. Instead, passive control is achieved by preparing the gas beforehand in a mixing chamber such that it will meet the proper initial conditions when admitted to the experiment chamber. The humidity would not be monitored or controlled thereafter. Active control of relative humidity during an experiment is required for a number of strawman experiments, indeed many scientists consider it essential. To control relative humidity and to ensure a reasonable degree of uniformity, however, may seriously disturb the experiment. At a minimum, a humidity sensor must be installed inside the chamber, keeping in mind that the measurement accuracy will probably be more important than control accuracy for most experiments. The measurement of relative humidity (in the mixing chamber) by measuring the water content with a gas chromatograph (as suggested in the GGSF concept design) would be difficult. Absolute water content down to less than 1% relative humidity (even as low as a few parts per million) can be measured by a few commercially available instruments. These should be investigated for use in microgravity.

Chamber Accelerations

Chamber accelerations should be monitored; this would give the direction and magnitude of residual gravitational acceleration (settling direction) that is needed, for example, in collision experiments, and might help to explain any features in data which may be caused by acceleration spikes. However, measurement of the acceleration at the chamber itself may not be required, as the data provided by the Space Station may be sufficient. Additionally, it is important to get an idea of the magnitude and effect of vibrations. Studies of vibrational coupling must be made for particular experiments where it could be important. For example, if the measurement of a sample's position is to be achieved with a video camera, vibration-induced relative motions between the camera and the experiment might be minimized by attaching the camera to the chamber and applying some vibration isolation technique. Yet, such a system may be difficult to work with in regards to the replacement of cameras, lenses, etc.

4.2 AEROSOL PROPERTIES MEASUREMENTS

An aerosol is a suspension of liquid and/or solid particles in a gas. Aerosol particle properties to be measured include concentration (number and mass), size or size spectrum, shape, structure, composition and, for biological experiments, viability and growth of the sample. Measurement of these properties may be needed as a function of time and are required for the strawman experiments. How these properties will be measured depends on an engineering-recommended solution for which, in many cases, the experimenter has offered suggestions. The actual methods chosen will be the result of weighing many factors including invasiveness, accuracy, cost, size, and mass. To measure the particle size spectrum, for example, it is possible to use video (possibly microscopic), scattering, a condensation nuclei counter (CNC) in combination with an electrical mobility analyzer or a diffusion battery, etc. Depending on particle size, concentration and the factors mentioned above, one method may stand out as the obvious choice. Both in-line (*in situ*) and off-line techniques should be considered. The advantage of employing in-line methods is that they are generally less invasive to the experiment.

Off-line Measurement Techniques

Some commercially available off-line diagnostic devices used in particle size spectrum analysis and their ranges are listed in Table 4.2–1. All of the instruments listed have limitations on their use such as the sizes and concentrations of particles which may be analyzed. For example, optical particle counters (OPC), instruments which use scattering techniques, are used for particles larger than are appropriate for condensation nuclei counters. A charge coupled device (CCD) video may be used for even larger particles in conjunction with software for counting and sizing.

Table 4.2–1. Commercially Available Off-Line Diagnostics for Size Spectrum Analysis

Diagnostic	Particle Diameter (μm)	Concentration (particles/cm^3)
Condensation nuclei counter* (CNC)	~ 0.01 to ~ 3	0.01 to 10^7
Diffusion battery*	0.005 to 0.2	0.001 to 10^7
Electrical mobility analyzer*	~ 0.01 to ~ 1.0	10^3 to 10^7
Optical particle counter (OPC)	0.1 to 100	up to 10^3

* The CNC counts particles without regard to size (within the range specified). The diffusion battery and the electrical mobility analyzer both require a CNC or another particle counting mechanism in order to correctly measure the particle size spectrum.

Off-line techniques require a sample to be drawn from the chamber, which could disturb the experiment conditions. In order to minimize the impact on the experiment, the sample drawn should be as small as possible. The sample could then be diluted outside of the experiment volume to provide the larger volume and higher flow rate often required by these devices (development work could be done to reduce this requirement). The sample must be diluted immediately so that the concentration does not change in the interim; high concentrations can typically drop an order of magnitude in a few seconds. Also of concern is the potential for loss of particles to tubing walls between the experiment chamber and the measurement device. This tendency is especially great for particles smaller than 0.1 μm, due to diffusion, and for particles larger than 5 μm, due to inertial deposition.

In-line Measurement Techniques

In-line (*in situ*) aerosol measurements do not require the drawing of a sample from the chamber and are less invasive to the experiment. Spectral measurements are the primary in-line aerosol diagnostic and are discussed further in section 4.3; other in-line diagnostics such as optical imaging are discussed in section 4.4. Experimenters report that it is feasible to measure particles down to tens of nanometers in the laboratory using scattering and polarization methods. A restriction on scattering measurements is that there is a region, from 1% to about

85% light extinction, outside of which useful sizing and concentration information cannot be extracted and another method would have to be used. It is also noteworthy that for a cloud with a narrow particle size distribution (i.e., monodisperse), the distribution may be determined from scattering data. For a cloud with a more complex size distribution (i.e., polydisperse), it is more difficult to infer the size distribution from scattering data.

4.2.1 Overview of Technical Requirements

The aerosol measurement requirements for the strawman experiments call for measurement of particle sizes from the microscopic to the macroscopic. The wide range of aerosol particle materials required includes silicates, carbon soots, tholins, ices, and metals. Particles range from single grains or drops to large aggregates or agglomerates and include fractal aggregates, crystals, water droplets, refractory grains, glass microspheres, bacteria in aqueous droplets, and filamentary smoke (e.g., MgO) agglomerates.

The particle size spectrum as a function of time requires measurements within the 0.01 μm to 1 cm size range. Aerosol number concentrations requiring measurement as a function of time fall within the 1/cc to 10^{10}/cc range. These ranges are based on particle size and number concentration information in the Experiment Information Database, but may not reflect the particle sizes and concentration for which measurements are desired. For example, it may be that an experimenter who generates 10 nm particles has no interest in taking measurements until they have formed 500 nm aggregates. Such information is crucial to developing accurate experiment requirements and presently is not specified in the database.

Although not specifically called out as a requirement, the spatial uniformity of particle distribution is a measurement that may be important for many experiments. Mass concentration as a function of time is also required. Required morphological measurements, in addition to size and shape (or deviation from spherical), include relative abundances of species in mixed aggregates, bulk density or filling factor (fractal structure), surface texture, and thickness of frost coating. Measurement of the loss of material to the chamber walls (wall deposition) is also required; both rate and total loss may be of interest. Other sample properties of interest include the shear strength of an aggregate, index of refraction, charge, orientation of filamentary agglomerates in an electric field, and microbial growth (organisms per unit of volume).

In order to properly define the range of the aerosol measurements to be taken, experimenters must provide the project with some additional information. Not only is it important to know the initial conditions of the aerosol (size, concentration, etc. and tolerances) for generation and dispersion purposes, but the initial conditions for its observation are also important. Further experiment definition studies may be required to develop observation requirements.

4.2.2 Workshop Comments & Findings

There should be no attempt to develop new aerosol, or other, measuring devices for the GGSF. Existing devices and techniques should be tested and modified if necessary to function in microgravity and to meet size and other GGSF constraints. Initial conditions for aerosol measurements must also be well-defined.

An effort should be made to measure the particle size spectrum as far as possible below 0.01 μm (lower limit suggested in the GGSF concept design), because it is important to know both the initial as well as the final particle distributions.

The GGSF program should not focus on developing new technology for measurement, but rather on improving or adapting techniques already in existence. As an example, a tapered element oscillating microbalance (TEOM*) is a useful instrument for monitoring mass. It works especially well for soot or low density metals. It could be modified (miniaturized, etc.) to work on the GGSF.

Technology has never been pushed, in the area of off-line diagnostics, to work with a small sample volume since this has not been a requirement for ground-based work. This could be a fertile area for future development.

An electrical mobility analyzer would be a useful diagnostic for GGSF; however, ground-based versions are too large and flow rates too high. A smaller version could be developed for GGSF which could be used at discrete times rather than continuously.

Whether condensation nuclei counters will operate properly in microgravity is not clear. Questions such as, "Are standard CNCs gravity dependent?", "Have they been used in space before?" should be investigated.

A diffraction technique for particle sizing in which laser light is diffracted by the particles and then passed through a lens to form an interference pattern was proposed in the GGSF concept design. This method, however, may not be applicable to non-spherical particles and so, in general, may not be useful for aggregates. Further study and experiment definition using this technique is warranted.

* Rupprecht & Patashnick, Inc., Albany N.Y.

4.3 SPECTRAL PROPERTIES MEASUREMENTS

Spectral properties that are important in many GGSF experiments include scattering, polarization, transmission (extinction), absorption, and emission. Of these properties, only emission measurements might not require a photon source. Spectral properties may be measured for a single particle or for a cloud of particles, and they generally require both a source and a detection system with specified characteristics. The required source may be broadband or a single frequency. A single frequency may be selected from a broadband spectrum using a monochromator or a filter wheel, or generated by a laser (tuneable or single frequency).

Scattering

A typical measurement which might entail the use of a tuneable laser would require knowledge of the central laser frequency, bandwidth, and source intensity along with their associated tolerances. With the initial direction of the laser beam as a zero reference, photons would scatter either elastically (exit with the same frequency) or inelastically (exit with a different frequency) at various angles from the beam. Single particle scattering is often assumed when the concentration is not too high, but this assumption breaks down at higher concentrations (optical depth greater than about 0.01), in which case the more complex multiple scattering theory must be used. Often, symmetry may be invoked and detectors only need to be placed from 0 to 180°. The detectors (which are basically photon counters) measure the intensity with respect to angle at each discrete detector and from this the photon intensity as a continuous function of scattering angle may be inferred. Angular resolution of each detector element (which depends on its area and field of view) is an important parameter in the calculation. If the scattering is elastic, the detector frequency is the same as the source frequency and frequency discrimination at the detector is not needed; however, if the scattering is inelastic a means of frequency discrimination (e.g. a diffraction grating) at the detector site is required. In the following paragraphs brief descriptions of other spectral measurements will be discussed, most of which have much in common with scattering measurements. Points of commonality will not be repeated.

Polarization

These measurements may be accomplished by irradiating the sample with photons of known polarization (e.g., linear, circular) and calculating the degree of polarization at the detector site from photon counts using the scattering theory, or by using polarizers at the detector site to measure the scattered photon polarization. The first method is computationally more difficult, while the second requires more complex hardware.

Absorption

Measurements are performed to determine if photons of a particular frequency are being absorbed (through electronic, vibrational, or rotational transitions) by a particle or cloud of particles. If absorption does occur and is the dominant mechanism of photon beam loss, the intensity of the transmitted beam will be reduced at the absorption frequency. If, however, angular scattering also occurs, photons will also be lost from the beam due to that mechanism and the results must be properly interpreted to infer photon absorption.

Transmission

Extinction or transmission measurements provide the optical depth of a particle cloud, usually at a particular frequency. The ratio of the detected intensity to the source intensity at 0° (which may vary from 0 to 1), is a simple measure of the loss of photons from the beam due to scattering and/or absorption.

Emission

These measurements involve detection of photons emitted from particle clouds or single particles. These emissions may be the result of the absorption and subsequent inelastic re-emission of incident radiation or they could also be the result of thermal radiation where the particles were not necessarily excited by a photon source (e.g., thermal conduction). Emissions may be weak and possibly isotropic. Emissions detectors must generally be more sensitive and have a larger surface area in order to detect sparse streams of photons. Fluorescent emissions, for example, may be very weak, as in one GGSF strawman experiment where the rearrangement of the surfaces of two crystals upon collision to a lower energy configuration will produce photon emissions possibly on the order of single photons.

Many physical properties can be deduced from spectral measurements. In fact, it has been suggested that most experiment sample characterization in the GGSF might be accomplished through this method of measurement in order to reduce the impact on the evolution of the experiment. In spite of the apparent advantage of this approach, most of the required sample characterization can be accomplished through other techniques, spectral measurement being only one possible solution.

The major focus of several GGSF strawman experiments is characterization of the spectral properties of materials and structures. In some cases, the experiment is an attempt to decipher spectral data from astronomical sources by cataloging the spectral properties of materials and structures that may exist at these sources. In these cases, the properties of interest can not be measured in any way other than by spectral measurements.

4.3.1 Overview of Technical Requirements

Those GGSF strawman experiments which include spectral properties measurements have a broad range of requirements. The photon source ranges from broadband (e.g., a tungsten lamp) to single frequency (e.g., He-Ne laser). Wavelengths required range from 0.17 to 30 μm —

from ultraviolet (UV) to infrared (IR). Some require polarizing filters. Requirements on the source bandwidths, the intensity versus frequency profiles of the light source, and the tolerance on the source wavelengths have not yet all been acquired for the strawman experiments.

Detectors for scattering must span scattering angles from 0 to 180° and must be sensitive through the wavelength range specified above. All requirements (including tolerances) for angular resolution, detector sensitivity, detector spacing and field of view have not yet been acquired for the Experiment Information Database.

4.3.2 Workshop Comments & Findings

Wavelength range

A critical issue for spectral properties measurements concerns the wavelength range over which sources and detectors must operate. The strawman experiments had wavelength requirements of 0.17 to 30 µm, but the GGSF concept design narrowed that range to 0.2 to 2.5 µm. Not only does the reduced range seem quite narrow, it may be important to extend the wavelength range beyond that called for in the strawman experiments in order to study important features which could be pertinent to future GGSF experiments (see Appendix F). A diagnostics wavelength range from 0.17 to 50 µm would offer reasonable initial capability, but extending this range down to 0.16 µm and up to 300 µm should be considered as an upgrade to the facility at a later time. Arguments against the longer wavelengths include the problems of window materials and the complexities of the cryogenic cooling necessary to perform this detection.

Detectors

The detector ring suggested in the concept design would cover 180° at 10° intervals. In many scattering experiments, however, it may be advantageous to have non-linear spacing for the detectors to reflect the common sin $(\theta/2)$ dependence. It is also important that the detectors in the proposed detector ring have a limited field of view so as to provide adequate angular resolution. For instances where very weak signals need to be detected (e.g., emissions from single particles), new solid state PMTs (photomultiplier tubes) might be considered. In addition to having the capability to measure angular scattering, the capability of measuring total scattering using a device such as a cosine sensor would be desirable; a nephelometer system with fiber optics could also be used for this purpose.

Windows

Appropriate window materials for wavelength ranges must be considered. Fused quartz, for example, is relatively transparent down to 0.22 µm and up to 5 µm where it becomes absorbing. Cooled quartz is a possibility for higher wavelengths. Factors which must be considered, in addition to transparency, when selecting these materials should include cost, strength, ease of cleaning, thermal properties, etc.

The issue of window cleanliness is critical to spectral properties measurements. The ability to keep the windows (and the detectors, if located within the chamber) clean is a problem which must be dealt with if accurate spectral measurements are to be obtained. Strategies for dealing with this problem are discussed in section 4.1.

Other

Raman spectroscopy should be considered as a possible GGSF diagnostic tool (Appendix F). It provides information not available by other methods and is especially useful for studying carbon.

University expertise should be utilized in technology development activities within the spectral properties measurement area to assure that technical requirements are best defined and met.

4.4 GEOMETRIC AND KINEMATIC PROPERTIES MEASUREMENTS

GGSF diagnostics in the area of geometry and kinematics refer to morphologic (shape and structure) measurements and to those which determine the position, velocity and acceleration (both linear and angular) of particles. The morphologic characteristics of interest include crystal and aggregate shapes, surface textures and associated optical properties (reflection, absorption, and emission as a function of wavelength). It will be necessary to gather statistical as well as morphological data concerning surface textures, mean grain size distribution in aggregates, relative abundances of species in mixed aggregates, and thickness of frost coatings. Kinematic measurements include such items as encounter geometry between colliding particles (e.g., impact parameter) and their velocity and acceleration before and after impact regardless of whether the particles bounce, stick, or fragment. Angular velocities and accelerations, including the orientation of the spin axis, are also important. Particular experiments may require inclusion of one or more of these diagnostics.

4.4.1 Overview of Technical Requirements

The strawman experiment requirements include particles in the 10^{-5} to 3 cm size range, with speeds of up to 10 cm/s. For these particles, different experiments will require the determination of morphological and kinematic properties; quantitative properties will require measurement with acceptable resolutions, accuracies, and uncertainties. The resolution criteria include the video frame rate, which must provide temporal resolution greater than the phenomenon being investigated. For example, to measure the coefficient of restitution from a collision of two samples, the requirements on sample velocities, the dimensions of experiment volume of interest, and the number of data points required to obtain good statistics may be sufficient to define the video frame rate requirements. Statistical analyses will be required to cope with uncertainties and to develop insights which are intrinsically statistical, for example velocity or size probability distribution functions.

Imaging is the natural choice for measuring many of these properties but alternative methods are available. Rotation rate and rotational acceleration, for example, may be measured through light scattering. Determination of the morphological characteristics of sample particles which are too small for visual examination may require the application of other techniques such as polarization measurements. This technique is suggested in one strawman experiment for investigating filament formation in an electric field.

Many of the strawman experiments request video data, of yet-to-be-determined resolutions and accuracies. Video imaging utilizing macro and micro lenses can be interfaced with image analyzing software which, in principle, would allow the acquisition of large data sets. The qualitative video requirements which have been identified include the following:

- high speed;
- adequate field of view and depth of field to image both aggregates on the centimeter size scale, and individual particles on the micrometer scale;
- the maximum camera jitter relative to the experiment sensitive volume must be less than the object being viewed;

- stereo capability, with zoom and magnification up to at least 50x;
- two and possibly three orthogonal cameras with microscopic capability for texture analyses;
- combined VCR and digital data acquisition for on-line or later analysis.

4.4.2 Workshop Comments & Findings

A number of concerns involving geometric and kinematic measurements must be addressed in the GGSF design and in the planning of GGSF experiments:

- The illumination technique must be matched to the experiment according to several criteria. First, the sensitive volume of the experiment is defined by the intersection of the field of view of the objective lens and the illuminated volume. Therefore, the illumination condenser optics and the objective lenses must be matched. Furthermore, the illumination intensity must not exceed limits, to be determined, above which photophoresis and thermal effects perturb the experiment.
- Simultaneous requirements for high-magnification examination of particles, and relatively low-magnification imaging for trajectory analyses may be incompatible. These two types of data require essentially different optical systems, and the high-magnification lens system may actually obscure the particle sample from the view of the low-magnification system.
- The optical system utilized for trajectory analysis may either be stationary, in which case the trajectory information is limited to the field of view of fixed lenses, or may be an actively-servoed system designed to track particles. Active control would require that the particle concentration be small enough that one particle could be tracked without interference from others, as well as a method of providing a tracking feedback signal. The requirements for active control are not yet determined.
- If the experimental particles are suspended in a gas, free or forced convective motions of the gas must be negligible with respect to the particle phenomena (e.g., collisions) being investigated. Tracer particles suspended in the gas may provide a useful indicator of these motions.

There are several diagnostic techniques which should be considered in the next GGSF design phase:

- By casting a thin sheet of illumination through a cloud of particles, a well defined observation volume is formed.
- Strobe lighting for imaging may help to limit the input energy of illumination and allow velocity measurements.
- Periodicity in reflected radiation can allow determination of rotation rates even if the particles are too small to image in more than one pixel.
- Laser Doppler Velocimetry (LDV) techniques may be used to measure both linear and angular velocities, rather than using a high resolution video.

CHAPTER 5

SUMMARY AND PROJECT RECOMMENDATIONS

This chapter summarizes the comments and findings generated at the 1992 GGSF Science Workshop. In addition, it presents the GGSF project's recommendations based on these comments and findings and concluding remarks about the workshop.

5.1 SUMMARY OF COMMENTS AND FINDINGS

Science Goals

In general, the GGSF science goals (as discussed in Chapter 2) are considered sufficiently broad to encompass the full range of science research that might benefit from such a low-gravity facility. The workshop pointed out a few instances where research areas were not specifically identified in the GGSF goals, and no current GGSF strawman experiments represented these areas. Some of these are discussed in the sections on biology and on astrophysics, physics, and chemistry (e.g., low-gravity microbiology studies, experiments in microgravity fullerene production, and studies of gas-grain catalysis).

The GGSF Science Working Group should review and make recommendations to NASA Headquarters on the science goals of the project. These goals should be expanded to encompass, as much as possible, the entire range of research areas for which this facility may be appropriate (see Chapter 2).

Science Return—Project Effectiveness

Workshop suggestions for improving the project's effectiveness in achieving its goals and for increasing the science return fall into two categories: experiment development, and technology development. In the area of experiment development, the project was urged to ensure that sufficient ground-based research preceded any orbital experiment. This ground-based research should focus on several questions:

- Does the experiment actually require the long-duration microgravity environment of the GGSF, or can the experiment's hypothesis be tested adequately in a ground-based laboratory or sub-orbital platform?

- Will the experiment be productive given unexpected changes in the background acceleration, or any other variations in experiment parameter space that are beyond the experimenter's control?

- How much of the experiment outcome is determined by microgravity and how much by the containerless aspect of the microgravity experiment?

In the area of technology development, the workshop findings warn against risking the project's success on new technology development. If at all possible, the project is urged to use existing technology and standard laboratory techniques (modified as little as possible), and to adapt them to the microgravity environment. To further minimize risks to the project, technologies identified as important to GGSF success should be demonstrated to be compatible with low-gravity operations through testing on low-gravity airplane flights (Learjet or KC-135) or Space Shuttle flights.

Since the project's success depends on the successful conduct of future GGSF flight experiments, the GGSF science community should be prepared for space-based research by first conducting experiment concept definition studies in ground-based laboratories and by conducting initial small experiments on low-gravity facilities such as drop towers, aircraft (e.g., NASA's KC-135), and Shuttle mid-deck. To that end, the project recommends that the science community be kept apprised of relevant funding mechanisms and, as soon as possible, additional funding should be made available for such a microgravity experiment concept development and a small experiments flight program.

Key GGSF subsystem concepts and functions should be tested in low-gravity environments through, for example, a series of sub-orbital or Space Shuttle trials. These flights might serve a dual purpose as engineering concept demonstration flights and as early science experiments.

Bright Ideas" and Technical Suggestions

Many of the workshop findings can be placed in the category of "bright ideas" and suggestions for solving technical problems. These problems include cleaning the experiment chamber, measuring temperature and pressure, generating and dispersing sample particles, measuring particle sizes and shapes, measuring and controlling electric charges on particles, and many more. Many of the suggestions refer to techniques currently used in research laboratories, although most are not necessarily common practice.

Prior to future GGSF development phases, an in-depth survey (e.g., through a GGSF technology workshop) should be conducted to identify current laboratory procedures used by the GGSF science community and commercially available techniques which are appropriate for the GGSF, and to provide further understanding of and insight into the technical requirements for the GGSF.

Strawman Experiments

Several ideas for new strawman experiments for the GGSF representing a wide variety of research areas were put forward at the workshop. Some of these ideas have since been developed into strawman experiments. By working with the project in developing a broad variety of viable strawman experiments from which to draw the Facility requirements, the science community helps to ensure that the Facility will indeed facilitate the science envisioned for it. So far, none of the strawman experiments have been reviewed for appropriateness. Acceptable strawman experiments should have the following characteristics:

- There must be a clear need for long periods of microgravity. Any experiment that might be performed in a terrestrial or sub-orbital laboratory (as discussed in Chapter 1) is not a valid candidate.
- The GGSF must be the most appropriate microgravity facility for this research. Experiments that are found to be more appropriate for another existing or planned microgravity experiment facility should be referred to that facility's developers.

Interested scientists are encouraged to submit strawman experiments to expand the requirements base to which the GGSF will be designed. The project also recommends that the GGSF Science Working Group review all strawman experiments to ensure that the experiments meet GGSF science objectives, require microgravity, and that their technical requirements (as documented in the Experiment Information Database) are feasible for incorporation into facility requirements and represent a specified level of maturity.

Requirements

Many of the workshop findings deal with the incompleteness of the GGSF project Experiment Information Database (EID); this database is key to developing technical and functional requirements for facility hardware. Although it might be argued that some requirements not explicitly identified could be derived from other information in the EID, the lack of explicit mention of a requirement could easily be interpreted as an indication of low priority. Additionally, there are many "holes" or missing data in the EID resulting from a current lack of definition of some experiment requirements. Further development of GGSF experiment concepts is required to fill in such "holes" in the EID.

Many of the "holes" in the requirements documentation concern descriptions of experiment initial conditions (e.g., spatial homogeneity of a particle cloud, particle size distribution, monodispersity versus polydispersity, electrical charges on particles, etc.) that are important in particle generation and sample handling designs. Others concern characterization of the environment (the need to measure externally applied accelerations, more precise definition of the location of measured temperatures) that determine the diagnostics needed in the facility.

Perhaps the most important requirement documentation "hole" concerned cleanliness of the experiment chamber. This topic seems to have pervaded all workshop discussions, and for good reason. Many GGSF experiments will involve clouds of particles, at least some of which will reach the chamber walls (and windows, and access ports, and diagnostics sensors, etc.). Sample materials sticking to any surfaces inside the chamber can cause problems such as the following:

- contamination of an experiment's gas mixture due to outgassing of residual materials from previous experiments or previous runs of the same experiment;
- potential gas leaks at the chamber's vacuum seals after on-orbit cleaning attempts;
- degradation of diagnostic signals by particles deposited on sensors and optical ports.

The Experiment Information Database (EID) must be expanded to include new fields/data that better document requirements such as chamber cleanliness. Given the importance of chamber cleanliness to the GGSF design, the project recommends that study and resolution of this issue in particular be given high priority in future design activities. Additionally, funding and research opportunities must be made available to the GGSF science community for further development of GGSF experiment concepts before many requirements "holes" in the EID can be eliminated.

Parameter Ranges

In addition to the areas mentioned above in which the workshop found the EID to be incomplete, many of the workshop findings indicate that several parameter ranges for requirements currently specified in the EID need review. For example, extending the low temperature capability below the current 40 K could greatly increase the range of research that the facility would support. A similar increase in research potential would be realized by extending the low pressure limit below the current microbar level. The range of measurements possible through optical (spectral) diagnostics could be greatly increased by extending the wavelength range over which light sources and detectors must operate. Additionally, there are instances in which the Phase A concept design reduced the parameter range to be accommodated relative to the ranges specified in the EID.

Parameter ranges in the Experiment Information Database should be reviewed with the intent of accommodating the widest range of research. Any reduction in a given parameter range should only be the result of engineering trade-off studies and should be weighed carefully against science impact.

The phase A concept design presented by TRW Space and Technology Group was received with a great deal of enthusiasm. The workshop did, however, identify a few areas in which the phase A concept design overlooked requirements specified in the EID. These oversights include the following:

- the inability to monitor or control the relative humidity within the experiment chamber;
- the inability to monitor environmental accelerations (e.g., gravity, vibrations, etc.) at the experiment location;
- the possibility of unwanted chemical reactions catalyzed by materials from which the experiment chamber is constructed;
- the lack of a means of monitoring and controlling the static electric charge on sample particles; and
- the lack of a strategy to deal with sample particle deposition on the chamber walls and windows, and the impact this will have on experiment gas composition and on optical diagnostic measurements.

Aspects of the Phase A concept design cited at the workshop as insufficient for accommodating the current requirements will be recommended by the project for further study in future Facility development phases.

5.2 CONCLUSIONS

The primary purposes of this report are to convey and document information disseminated at the May 1992 GGSF Science Workshop in Las Vegas, Nevada, and to record and respond to the community's review of the (Phase A) GGSF design concept and of the GGSF science objectives and technical requirements carried by the GGSF project. Much was accomplished at this workshop which is not adequately conveyed in the pages of this report and hence merits a few words here.

As mentioned in Chapter 1, the GGSF Science Workshop was organized with the following objectives: to foster dialog between the science community and the project hardware developers; to continue to define and refine the science and technical requirements for GGSF; to obtain feedback from the science community on the Facility design concept study; and to encourage discussion within the science community on related individual research interests and activities. The workshop was highly successful in meeting these objectives, largely due to the active and dedicated participation of the science community. Many scientists presented their research in the plenary sessions of the meeting, and many others shared their research results and needs in the poster session which was well attended by all of the workshop participants.

The splinter group meetings, or working sessions, which were led by members of the GGSF science community, were the center of many wonderful discussions which took place over the last two days of the workshop. In those sessions, not only did the science community provide valuable information relating to the adequacy of the GGSF concept design to meet their scientific needs, but each member contributed to a dynamic flow of ideas, exploring how to conduct their research in low-gravity — how to develop experiments that are both simpler and more effective; addressing commonly shared problems and concerns, such as contamination of windows; comparing notes on measurement techniques; and generally showing a great deal of interest in sharing useful and helpful information. The unique and synergistic nature of this multi-disciplinary community was evident in these sessions. Perhaps only there would one expect to hear an atmospheric scientist ask a microbiologist for microbial samples to use as condensation nuclei in his experiments!

Clearly the Gas-Grain Simulation Facility project benefits greatly from ongoing communication with and participation of the science community at large. Future workshops convening the GGSF science community are very much warranted to ensure that the important science objectives and research interests of this community are carried forward in NASA planning and that appropriate ground-based and orbital research opportunities become available as soon as possible.

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Appendices

Appendix A

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Appendix B

Workshop Agenda

Gas-Grain Simulation Facility (GGSF) Science Workshop
Desert Research Institute (DRI), Las Vegas
May 4, 5, 6, 1992

Chairmen, Plenary Sessions:
Huntington, Rogers

MONDAY, MAY 4, 1992

8:00	*REGISTRATION & CONTINENTAL BREAKFAST*	
9:00	Welcome to Desert Research Institute	Tarank
	Opening Remarks	Huntington
9:15	Life Sciences Flight Program at NASA HQ	Fogleman
9:35	GGSF Project Overview: Goals and History	Huntington
10:05	*BREAK*	
10:20	GGSF Project Overview: Organization and Status	Fonda
10:40	GGSF Heritage: Case History of the Atmospheric Cloud Physics Laboratory	Kocmond
11:10	Airborne Particulate Matter & Spacecraft Internal Environments	Liu
11:30	Particle Dispersion Experiment on Shuttle	Marshall
12:00	*DRI HOSTED LUNCH*	
1:00	Organic Compound Synthesis on Growing Particles	Oberbeck
1:20	Cirrus Crystals in Low Gravity and Measurement of Their Radiative Properties	Hallett
1:40	Planetary Atmospheres and GGSF	Pope
2:00	The Cost and Joy of Low-Gravity Experimentation	Stratton
2:20	GGSF Experiment Requirements	Greenwald
3:00	*BREAK*	
3:20	GGSF Concept Design	Gat/TRW
5:30	*ADJOURN*	

GGSF Science Workshop
Agenda

TUESDAY, MAY 5, 1992

8:00	*CONTINENTAL BREAKFAST*	
8:30	Micro-Gravity: A Tool for Aerobiology	Mancinelli
8:50	Particle Dynamics in Ring Systems: Limitations of Earth-Bound Experiments	Bridges
9:10	Instructions to Splinter Groups	Huntington
9:30	Discussion Groups	
10:30	*BREAK*	
10:45	Discussion Groups	
12:15	*LUNCH*	
1:45	Discussion Groups	
3:15	*BREAK*	
3:30	Discussion Groups	
5:00	Poster Session with Social Hour	
6:00	*ADJOURN*	

WEDNESDAY, MAY 6, 1992

8:00	*CONTINENTAL BREAKFAST*	
8:30	Discussion Groups	
10:00	*BREAK*	
10:15	Discussion Groups	
11:45	*LUNCH*	
1:15	Discussion Group Reports	Group leaders
2:30	*BREAK*	
2:45	Discussion Group Reports - cont.	Group leaders
4:00	Closing Remarks	Rogers, Huntington
4:10	*CLOSE OF WORKSHOP*	
4:20	Tour of University of Nevada at Las Vegas & Social Reception	
6:00	*ADJOURN*	

Discussion Group Schedule

Tuesday, May 5			Wednesday, May 6	
9:30 AM	1:45 PM	3:30 PM	8:30 AM	10:15 AM
Science Discipline Discussion Group: **BIOLOGY AND EXOBIOLOGY** Room: 181	Sample Generation and Handling Discussion Group: **DISPERSED LIQUIDS** Room: 181	Sample Generation and Handling Discussion Group: **DISPERSED SOLIDS** Room: 181	Sample Generation and Handling Discussion Group: **HIGH TEMPERATURE FORMATION AND SAMPLE HANDLING** Room: 181	Sample Generation and Handling Discussion Group: **AMBIENT TO LOW TEMPERATURE FORMATION AND SAMPLE HANDLING** Room: 181
Science Discipline Discussion Group: **PLANETARY SCIENCE** Room: 182	Diagnostics Discussion Group: **ENVIRONMENT MEASUREMENTS** Room: 182	Diagnostics Discussion Group: **GEOMETRIC & KINEMATIC PROPERTIES** Room: 182	Diagnostics Discussion Group: **SPECTRAL PROPERTIES MEASUREMENTS** Room: 182	Diagnostics Discussion Group: **AEROSOL PROPERTIES MEASUREMENTS** Room: 182
Science Discipline Discussion Group: **ATMOSPHERIC SCIENCE** Room: Library	Diagnostics Discussion Group: **GEOMETRIC & KINEMATIC PROPERTIES** Room: Library	Diagnostics Discussion Group: **ENVIRONMENT MEASUREMENTS** Room: Library	Diagnostics Discussion Group: **AEROSOL PROPERTIES MEASUREMENTS** Room: Library	Diagnostics Discussion Group: **SPECTRAL PROPERTIES MEASUREMENTS** Room: Library
Science Discipline Discussion Group: **ASTROPHYSICS, CHEMISTRY, & PHYSICS** Room: 252	Diagnostics Discussion Group: **SPECTRAL PROPERTIES MEASUREMENTS** Room: 252	Diagnostics Discussion Group: **AEROSOL PROPERTIES MEASUREMENTS** Room: 252	Diagnostics Discussion Group: **ENVIRONMENT MEASUREMENTS** Room: 272	Diagnostics Discussion Group: **GEOMETRIC & KINEMATIC PROPERTIES** Room: 272

Appendix C

Workshop Science Presentations

CHARACTERIZATION OF AEROSOLS AND ICES IN MICROGRAVITY

M.A. ALLEN, V. ANICICH, W.D. LANGER
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Many processes involved in gas-grain interactions and processes on grains are common to astrophysical, solar nebula, planetary and terrestrial science. We describe a concept configuration for the Space Station Gas-Grain Simulation Facility (GGSF) that would address a wide range of these problems that involve aerosols, nucleation, freezing and chemical processing. The GGSF is ideal for investigating these problems because the microgravity environment allows sufficient time for *in situ* formation of aerosols, characterization of their physical/chemical state, additional processing of the aerosols, and characterization of the consequent modified aerosols. We would use *in situ* formation of volatile condensates and characterize their physical and chemical states with IR extinction measurements. The corresponding haze would be processed with UV and visible light to form grain cores.

ICE CRYSTALS IN CIRRUS CLOUDS: ICE PARTICLE FORMS AND LABORATORY MEASUREMENTS OF THEIR RADIATIVE PROPERTIES

W. PATRICK ARNOTT & JOHN HALLETT
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Solar and terrestrial radiation transfer through the atmosphere are key to understanding and predicting global warming of so-called green house gases such as CO_2 and water vapor. Ice crystal containing clouds are a major thorn in the side of scientists computing radiation transfer in the atmosphere because of the variety and complexity of ice particle geometric forms encountered. In contrast, it is relatively easy to compute radiative transfer in clouds containing spherical water droplets because a precise solution for the absorption and scattering properties of a single droplet is available (and has been since the turn of the century). The scattering properties of ice crystals can be modeled using simple geometrical optics for wavelengths in the visible and near infrared, or solar spectrum. Geometrical optics can not be used for analyzing the mid infrared scattering properties because the wavelength is about the same as the crystal dimension. In addition, one can not gain intuition for analyzing mid IR scattering properties from those of visible wavelengths because the ice absorption spectrum is very different in these bands. Thus it is desirable to perform laboratory measurements of ice crystal scattering properties in the mid IR as a guide for developing accurate models for scattering. Current laboratory measurements suffer from the effects of gravity because ice crystals fall out before growing to sizes commensurate with naturally occurring cirrus clouds. The Gas-Grain Simulation Facility offers a unique experiment environment for producing ice crystal clouds similar in size and composition to naturally occurring cirrus clouds. We are interested in growing realistic cirrus clouds in low g and measuring their differential scattering, extinction, and absorption cross sections for both solar and terrestrial wavelengths.

THE DYNAMICS OF DENSE AND DILUTE CLUSTERS OF DROPS EVAPORATING IN LARGE, COHERENT VORTICES

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The behavior of evaporating clusters of drops embedded into large, coherent vortices is described using a formulation which is valid for both dense and dilute clusters. Drops and gas interact both dynamically and thermodynamically. Dynamic coupling occurs through a force on the drops due to drag resulting from a slip velocity between the two phases. The net interaction force on the gas with drops is due to a source thrust from evaporation plus drag on each drop. The drag coefficient accounts for blowing from the drop surface. Thermodynamic coupling is a result of drop heating and evaporation. Limitations due to drop proximity on heating and evaporation are taken into account.

The vortical motion of the drops in the cluster results in the formation of a core region devoid of drops at the center of the vortex, and a shell region containing the drops and surrounding the inner core. Results are presented showing the dependence of the evaporation time, the final to initial volume ratio and the final to initial shell thickness ratio upon the initial air/fuel mass ratio and as a function of the initial tangential velocities, upon the initial Stokes number, initial drop radius and initial outer cluster radius. Differences in behavior between and control parameters of dense and dilute clusters are pointed out by these new results. It is found that for dense clusters the final to initial volume ratio and final to initial shell thickness both scale with the initial Stokes number, a new result which must be validated experimentally.

PARTICLE DYNAMICS IN RING SYSTEMS: LIMITATIONS OF EARTHBOUND EXPERIMENTS

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Much of the structure observed in Saturn's rings (including the ring thickness, the distribution of particles and density waves) is determined by the dynamics of very low speed (0.01 cm/s–2 cm/s) collisions of water-ice particles. We have simulated these low-speed collisions using a water-ice particle connected to a long-period, compound pendulum; this particle (around 5 cm in diameter) collides with a flat water-ice surface. Our results (for zero impact parameter collisions) show that for very clean, smooth surfaces, there is very little energy loss in the collision for speeds up to 2 cm/s. The coefficient of restitution, $\varepsilon = (v_{out})/(v_{in})$, is in the 0.8–0.95 range. However, if the surfaces are roughed or coated with a thin layer of frost, ε drops considerably. The value of ε is still very high at speeds less than 0.5 mm/s but decreases rapidly with increasing collision speed. We expect such a surface to be more typical of the

surfaces on the ring particles of Saturn. Combining these results with a model of Goldreich and Tremaine leads to the prediction that the ring thickness is less than 10 m.

We also reported measurements of the sticking forces for frost-coated surfaces at impact speeds less than 1 mm/s. Usually sticking only occurs below a speed in the range 0.3 to 0.7 mm/s. The measured sticking forces (for ~1 mm^2 area) are in the range 10–100 dynes. These sticking forces provide a mechanism for particle aggregation. Small aggregates, composed of small particles, (~10 cm diameter), could be stable in the gravitational tidal forces of Saturn with particle-particle sticking forces of order 100 dynes, but would be limited in size to order of 10 m. Higher sticking forces would be needed to hold larger objects together within the ring system.

Our present measurements provide some initial data crucial for modeling the dynamics of the ring particles in Saturn's rings. However, these experiments are severely restricted in two major aspects. First, the particles cannot rotate in collisions and the transfer of energy between rotation and translation cannot be investigated. We also cannot easily investigate sticking effects in partially grazing collisions. Second, the effective mass is large (approximately 450 g) as a result of the inertia of the pendulum itself. It is therefore not possible to change the effective particle mass very much to determine what role inertia plays in the surface energy loss during a collision. In particular, we cannot investigate the dynamics of small particles ~1 cm in diameter.

Measurements of the energy loss in low-speed collisions for a variety of impact parameters and particle mass, of energy transfer between rotation and translation, and of sticking forces in low-speed glancing collisions are needed before a detailed understanding of the ring dynamics can be achieved. These measurements cannot be carried out on Earth and require a very low g ($\leq 10^{-5}\ g_{earth}$), vibration-free environment.

Research supported by NASA grant NAGW–590.

Starlight Polarization and the Settling of Atmospheric Dust Clouds

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The aggregation of dust in planetary atmospheres and interstellar clouds is possible only when grain–grain collisions occur at low kinetic energies. Under these conditions aggregation will be controlled by short- and medium-range interactions between the colliding grains. Knowledge of the physical and chemical properties of grains is crucial to understanding two important processes: aggregation and alignment. Recent progress in laboratory studies indicate that oxide crystallites which have grown in an H_2O-laden medium tend to acquire O^- (positive hole-type) electronic charge carriers. Dormant at low temperatures, these charge carriers are activated in a UV radiation field. Once activated, they accumulate at the surface of the grains charging it positive with respect to the interior. Upon contact between two grains of slightly different chemical composition, charge equilibration is expected to occur by positive holes flowing from the grain with the higher O^- density to the one with the lower O^- density. The resulting aggregates carry a dipole moment which in turn affects the way they interact with each other and with other single grains during subsequent collisions: collisions involving dipolar grains will necessarily lead to elongated and, in the extreme, to filamentary aggregates. In the zero-gravity environment of interstellar space, when dipolar aggregates travel through the interstellar magnetic field, they are subject to a Lorentz force that produces a torque. This process provides a possible mechanism for the grain alignment as detected by the polarization of starlight in transmission or infrared emission from dust clouds. Filamentary growth is self-limiting because the probability for the addition of grains to side branches increases with increasing length. Preliminary Monte Carlo calculations indicate that the aspect ratio of dipolar aggregates goes through a maximum. Dipole–dipole interaction also affects the kinetics of aggregation through the formation of metastable patterns, characterized by cells with fluctuating walls. In a viscous gas medium and under the influence of gravity, filamentary aggregates tend to sediment faster than isotropic flakes of comparable mass. To lay the groundwork for more advanced Monte Carlo calculations of dipolar grain aggregates, laboratory experiments are proposed using Charge Density Analysis, a new technique which can provide unique information about surface charges and charge carrier mobility. In addition, dust fluidization experiments are proposed to be carried out under a variety of conditions to study the formation of filamentary aggregates from fine oxide and silicate grains, the orientation of such aggregates in an electric field, due to an acquired electric dipole moment, and their sedimentation in a gravitational field.

INFRARED EMISSIVITY OF EXTRATERRESTRIAL PARTICLES

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The purpose of the suggested GGSF experiment is to study the emission characteristics of individual grains of material gathered from the space environment. A broad spectrum of particle classes could be studied with emphasis going to interstellar and interplanetary dust grains gathered while in orbit. The idea is to measure the infrared emission from these rare individual grains and compare their properties to those deduced from classical astronomy.

Captured particles would be inserted into the experiment chamber and positioned using levitation. Levitation is required in order to decouple the grain lattice from any other material objects. After heating the particle, emitted gases will be sampled and the emittance spectrum measured. The advantage of such an experiment is that grains gathered while in orbit will be studied while in orbit and would not be contaminated by containers and terrestrial gases which could modify their properties.

SIMULATION OF LIGHTNING*

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We report the results of laboratory simulation of lightning, in gas mixtures pertinent to planetary atmospheres, using laser induced plasma (LIP) produced by Nd:YAG laser radiation. The laser beam is, typically, about 150 mJ energy per pulse at 1064 nm wavelength and 12 nanoseconds pulse width, focussed into a chamber fitted with windows and containing test atmospheres of Earth, Venus, Jupiter and Titan. The radiation emitted by the plasma is monitored spectroscopically yielding spectra of lightning simulations in the 300 to 850 nm range. We also report a comparison of pressure-temperature history of the natural lightning and lightning simulation in air which indicates that the two behave similarly in the temperature range relevant for chemical synthesis.

* Funds for the partial support of this study have been allocated by NASA-Ames Research Center, Moffett Field, CA under Interchange No. NCA2-382 and No. NCA2-508 and NSF-REU Grant #PHY-9000697.

** Currently with IBM Almaden Research Lab., San Jose, CA.

MICROGRAVITY: A TOOL FOR AEROBIOLOGY

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Bacteria are found in a variety of habitats including the air. The viability of airborne bacteria appears to depend on many atmospheric constituents including NO_x, relative humidity, and ultraviolet radiation. Increased levels of NO_x or ultraviolet radiation seem to decrease the survival of certain airborne bacteria. It is clear that some microbes remain viable while airborne, but it is not clear if they metabolize, and/or divide while airborne. As a consequence, it is unknown if airborne microbes can carry out metabolic reactions that affect atmospheric trace gas chemistry (e.g., NO_x chemistry) while airborne. The proposed research will address these issues. On Earth, gravity prevents a bacterial aerosol from being suspended for two to three weeks. For this reason, the only way to conduct experiments that will definitively address these issues is in a microgravity facility capable of aerosol research.

The data gathered to date from airborne microbiological laboratory and field studies, as well as observations from space missions suggest the following hypotheses:

1. Bacteria metabolize and divide while airborne.

2. There is significant interaction between airborne bacteria and atmospheric trace gases (e.g. NO_x). Because NO_x is an intermediate in denitrification, airborne denitrifying bacteria remain viable in the presence of gaseous NO_x longer than other microbes (i.e., natural selection occurs in the atmosphere). Denitrifying bacteria change the relative levels of NO, NO_2, and N_2O in the atmosphere through their metabolism.

3. In the microgravity environment (e.g., space station) potential pathogens can spread more readily than they do in Earth gravity.

These hypotheses can only be tested definitively in a microgravity facility, but it is first necessary to develop a protocol applicable to the study of aerosols in a microgravity environment. This requires answering some basic questions regarding microbial bacterial aerosols (ground based study) and microgravity, separately. For example, does microgravity affect microbial viability, growth or metabolism? (Results of some studies suggest that it does not—while others show some small effects.) The general questions pertaining to microbial aerosols include: Does the process of aerosolization and aerosol collection affect the microbes to be tested? If so, how? The ground based concept study proposed will answer these questions.

The objectives of the ground-based concept study proposed here are:

1. To screen candidate organisms to be used in the microgravity facility for the eventual determination of the survival, interaction, as well as possible metabolism and/or division of aerosolized denitrifying and non-denitrifying microorganisms when exposed to atmospheres containing and not containing NO_x. This will reduce the number of species of bacteria to be tested in the microgravity facility.

2. To assess the applicability of the spinning top and vibrating orifice methods for aerosol generation and the May sub-sonic impinger as a method for collecting the bacteria from the aerosol chamber in a microgravity environment.

3. To mathematically model aerosol disease spread in confined spaces under micro-gravity, such as would exist in the space station, using results obtained during the course of the research plus preliminary data already obtained.

To achieve these objectives the ground-based study proposed here will use the microthread technique as well as the rotating drum as an aerosol chamber. The spinning top technique will serve as the aerosolizer for the drum and the vibrating orifice will be used as the aerosolizer for the microthread experiments. The May sub-sonic impinger will be the aerosol collector. In addition, mathematic models will be developed that assess the use of the spinning top and vibrating orifice methods and the May sub-sonic impinger for microbial aerosol generation and collection in the microgravity environment. The ground based study proposed here will advance our understanding of fundamental aerobiological processes (e.g., airborne microbial metabolism and division) and develop technology for conducting aerobiology experiments in the microgravity facility.

PARTICLE DISPERSION EXPERIMENT (PDE)

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The PDE will fly aboard the first United States Microgravity Laboratory (USML–1) on Space Shuttle Columbia (STS–50) in July 1992. It will act as a "test-bed" for GGSF experiments that need to create a well-dispersed solid-particle aerosol in microgravity. It will also study the aggregation of the particles after their dispersal as a means of gaining insight into the role of aggregation in the cleansing of planetary atmospheres after the creation of atmospheric dust palls by aeolian activity, volcanic eruptions, and bolide impacts.

Limitations on crew time, technological and safety constraints imposed by the Shuttle flight environment, and budgetary limitations etc., demand that experiments of this type be highly focused scientifically, and that they be technologically simple and innovative. The experiment must also be designed to avoid "single-point" failures from either a scientific or an engineering standpoint. This can be achieved technologically through a multiple-unit (disposable modules) design, by design simplification, by limiting the number of experiment/Shuttle interfaces, and by fail-safe design concepts. The science can be safeguarded by placing realistic and very conservative expectations on the experiment, by providing test redundancy, by the collection of uncomplicated data, and by incorporating the null outcome of a test as part of the solution.

The PDE constitutes only one element of the GGSF precursor program that should include other reduced gravity environments such as the KC–135 aircraft, drop towers, and free-flying orbital platforms. The number of flight opportunities for such a program are rather limited, but the experiments proposed for GGSF are quite ambitious. It is imperative, therefore, to take advantage of every possible reduced gravity opportunity, no matter how "quick and dirty" it may be. A vast array of potential pitfalls awaits the Space Station GGSF experiment that has not completed a reduced-gravity apprenticeship.

RADIATION-INDUCED ROTATION OF INTERPLANETARY DUST PARTICLES UNDER MICROGRAVITY

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The main objective of this study is to investigate the dynamics of interplanetary dust particles (IDP) in space, and the possible dust particle fragmentation (rotational bursting) from the stress of very high spin rates (10^4–10^7 rot/sec). The mechanism that drives this particle spin-up is known as "The Paddack Effect" (S.J. Paddack first suggested this mechanism). The Paddack effect is generated by the interaction of solar photons with the surface irregularities of the particles, thus generating a torque for rotation. The sense of rotation is similar to a windmill. Rotational bursting is important since, in principle, repeated bursting of the IDP will reduce their size to the degree where they will be blown out of the solar system by the action of solar radiation pressure overcoming solar gravity (a mass loss mechanism). The first phase of this investigation is a ground-based laboratory experiment to study the rotation of particles by levitating simulated particles in a laser beam and under vacuum conditions (~10^{-7} torr), thus simulating space conditions. Four parameters will be determined: **a.** the rotation rate; **b.** the angular acceleration; **c.** orientation of the spin axis of the levitated particles; **d.** the effective moment arm of the rotation. Determining these parameters is essential in establishing rotational bursting of the particles. The second phase is to develop the concepts and methodologies of a flight experiment to observe this rotation mechanism under the microgravity environment of the Gas-Grain Simulation Facility (GGSF), to be flown on the Space Station Freedom. The IDP to be used in the flight experiment are the "Brownlee Particles" (collected by NASA's U2 planes in the Earth's stratosphere by Dr. D. Brownlee), and other man-made simulations of highly irregular particles. These particles cannot be laser-levitated on the ground since they will heavily absorb the high laser power needed to counter their weight and sublimate. For this reason the experiment needs to be carried out in the microgravity environment of the GGSF. Calculations were made to assess the laser power densities needed to position or confine the particle inside the laser beam, while the IDP are injected into the GGSF chamber. The laser beam confinement is needed to counter the residual forces inside the GGSF particle chamber such as: gravitation of ~10^{-1} g or less, Stokes g-jitter, and astronaut movements inside Space Station. These calculations showed that the needed power densities from a TEM* 01 mode (doughnut) He-Ne laser range from ~0.22 mW for a 40 μm particle, and up to ~28 mW for a 100 μm particle. These power densities are easily achievable for performing the experiment inside the GGSF particle chamber. Calculations were made to assess the equilibrium temperatures that the IDP will encounter via absorption (assumed albedo is 0.5) of the laser light, range from 360° C for particles of 40 μm in size, to 260° C for particles of size 100 μm. These calculations were made assuming a blackbody temperature. The laser beam will act as the light source for spinning the particles in order to shorten the time needed to measure angular accelerations, since it it will take several years for solar light to achieve the same result. This procedure is valid because the rotation rate and acceleration is linear with the intensity of the oncoming radiation. Measurements of the spin rate, spin acceleration, and orientation of the spin axis in space, will be made from identification of easily recognizable irregularities on the surface of the IDP. For determining rotation rates of a few Hz and faster, a pattern recognition spectrum analyzer of the scattered light from the IDP will be used. These measurements will be repeated for a statistically significant number of particles, from which we will determine an averaged "effective moment arm" that will indicate the strength of this mechanism with different surface irregularities of the particles. Results from this study will help to answer important questions such as: the contribution from this mechanism to the observed number density of the β-meteoroids leaving the solar system, its impact on the zodiacal cloud budget (i.e. supply vs. sink), the spatial dispersion of meteor streams, the synchronic bank structure in comet tails, and the feasibility of this mechanism in supplying interstellar dust from dust shell stars, Reflection Nebulae, etc.

ORGANIC COMPOUND SYNTHESIS IN RAINDROPS

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An important step in chemical evolution of prebiotic reactants leading to the origin of life on Earth was the polymerization of organic monomers. If monomers, such as amino acids were first in a dilute solution, molecules must first have been concentrated sufficiently that they came into contact with each other so that polymers such as polypeptides could form. Thus, environments such as tidal lagoons, aerosols, or raindrops have typically been considered as advantageous because evaporation can lead to enhanced concentrations and polymerization in such environments. Recent developments suggest that, after cometary impact, prebiotic reactants including amino acids occurred in concentrations in rain drops that were higher than those caused by traditional sources such as electric discharge. Nevertheless, whether the prebiotic reactants needed for chemical evolution were supplied by electric discharge or cometary entry, the reactants would have been present first in the atmosphere and they would have been cleansed from the atmosphere by rain drops. Evaporation of droplets and polymerization of amino acids should have been common after cometary entry because rain drop evaporation would have been the cause for downdrafts in convective clouds as it is in present clouds and because rain typically cleanses material from the atmosphere. Initial concentrations of amino acids in primordial rain drops may have been from 0.001M to 1M after cometary entry and these rain drops could have been evaporated during downdrafts and formed oligomers that were useful for chemical evolution.

An important reason that simulations of cloud drop prebiotic chemistry have not, as yet, been been performed is that rain drops cannot be suspended in a 1g environment for long enough time intervals so that cycles of wetting and drying can occur. Nevertheless, initial ground based experiments to crudely simulate evaporation of glycine amino acid water drops have been performed in our laboratory by placing them on Teflon pedestals and evaporating them with 100° C dry Helium gas streams. After several minutes, a solid film forms along the interface and then a thin film forms over the entire water drop. Analysis using liquid chromatographs and polyglycine standards suggest that long chain polypeptides formed. While progressive thickening of the interface between the water drop and the air on subsequent drying cycles indicates that these reactions occur at the liquid-air interface, we cannot be sure that they are not forming at the interface between the drop and the Teflon pedestal because we observed evaporation products forming first at the interface between the droplet and the Teflon substrate.

Because it requires typically two to three minutes for each droplet to evaporate and many cycles of wetting and drying for significant amounts of polyglycine to form, and because it is impossible to suspend such a droplet for the required time free of solid interfaces in a 1g environment, it will be necessary to use alternative suspension techniques such as levitation or reduced gravity in Space Station experiments to fully simulate prebiotic chemistry in rain drops. It is anticipated that levitation energy will eliminate the interface effects but it may introduce spurious effects due to the acoustic or electrostatic energy used to levitate the water drop. At this time it appears that the microgravity environment is the most promising way to accurately simulate prebiotic chemistry in raindrops following cometary entry in the primordial atmosphere.

PLANETARY ATMOSPHERES AND THE GAS-GRAIN SIMULATION FACILITY

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The clouds of Jupiter and Saturn play a key role in many fundamental aspects of these gas giants' atmospheres. Clouds affect the pressure-temperature structure, the penetration of incident sunlight, and the thermal emission, for example. Knowledge of the clouds' physical and chemical properties is therefore an important part of our overall understanding of the atmospheres and the planets.

Theoretical and spectroscopic evidence points to ammonia ice as the principal constituent of the uppermost clouds of Jupiter and Saturn. Another line of observational study which bears on the clouds is the measurement of the intensity and polarization of reflected sunlight, as performed by the Pioneer spacecraft. From these observations researchers derived the single-scattering properties that the upper cloud particles must have. In order to see if these scattering properties were consistent with ammonia ice crystals a laboratory experiment was devised to grow clouds of ammonia ice and measure their single-scattering properties.

The experimental set-up includes a tungsten lamp, a glass-walled cylindrical chamber, a liquid nitrogen reservoir, an array of photosilicon diode detectors, and a microscope objective through which photographs of the crystals are made. Using this apparatus the intensity and polarization phase functions for ammonia were measured over a range of temperatures from 130 to 200 K, and photographs were obtained of some of the larger crystals.

Two important concerns were made apparent by this laboratory work, and both could be addressed by a microgravity facility. First, it was determined that particles larger than about 6 microns in radius fell through the light beam so quickly that the light scattered by them could not be measured. In a microgravity environment larger crystals would stay aloft long enough to measure the light scattered by them. Second, the saturation level of ammonia vapor in the chamber had to be extremely high in order to produce clouds. In microgravity clouds could be produced under conditions more similar to the Jovian atmospheres where the cloud particles grow slowly in an environment of low saturation.

Titan is another outer solar system body with an interesting atmosphere. An important component of Titan's atmosphere is the global aerosol haze layer which obscures the surface from view and controls the penetration of sunlight. Understanding the aerosol particles is key to understanding many other aspects of Titan and its atmosphere. Laboratory efforts have addressed the size and shape of particles formed in a simulated Titan atmosphere. The need for microgravity has arisen in these studies in that researchers want to study: 1) particle growth for longer periods of time and to larger sizes than would remain aloft in 1 g, and 2) particle production at lower rates which are relevant for Titan's atmosphere.

CONFINING CHARGED DUST PARTICLES IN MICROGRAVITY

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The authors feel that the development of the Gas-Grain Simulation Facility for Space Station is an important step in the path towards understanding a number of phenomena. We are particularly interested in studying the interactions of grains and plasmas, as we feel that these have many important and interesting applications. Ground-based experiments can provide some useful insight into the care needed to perform meaningful experiments on small grain plasma interactions, but the advantages of microgravity experiments should not be missed. The Paul trap has long been used to study grain dynamics. A Wuerker Trap, we believe, would be a good trap for many studies of grain plasma interactions. In addition to trapping the ensemble of charged grains, plasmas and beams of charged particles can be inserted into the trap along the neutral lines. These advantages coupled with microgravity will allow studies of a number of puzzling questions. For example, the evolution of dust grains from small particles to larger conglomerates could well involve plasma interactions. These interactions suggest mechanisms which both hinder and enhance the growth of grains.

LABORATORY INVESTIGATIONS OF TITAN'S AEROSOLS

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Titan's aerosols are believed to have significant effects on the physical and radiative properties of its atmosphere. To investigate the physical properties of model Titan aerosols, experiments have been done in which acetylene, ethylene and hydrogen cyanide were photolysed separately and as a mixture by ultraviolet light. In general, the individual particles formed were spherical, apparently amorphous, and quite sticky. When 1 torr of C_2H_2 (in 55 torr N_2) was photolysed, the average diameter of the individual particles was about 0.6 μm and most (≈ 2/3) of the particles were found in non-spherical near-linear aggregates. The mean diameter of the particles decreased to 0.4 μm for 0.1 torr C_2H_2 and increased to 0.8 μm for 10 torr C_2H_2. Aerosols formed from photolysis of C_2H_4 were physically similar to those formed from C_2H_2. Photolysis of HCN rapidly produced particles that apparently did not grow to sizes (> 0.09 μm) large enough to be collected and imaged. The formation of particles from acetylene was observed within minutes in our experiments, but was slowed by about a factor of 4 when ethylene and hydrogen cyanide were added.

A NUMERICAL MODEL OF COAGULATION AND BROWNIAN DIFFUSION IN μ-GRAVITY

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The Gas-Grain Simulation Facility (GGSF) will expand current aerosol experiment capabilities by reducing gravitational settling and buoyant convection. However, Brownian diffusion will not be reduced. Loss of sample materials from the experiment volume to the walls through Brownian diffusion will cause time-dependent spatial variations in aerosol particle concentration and size distribution. These containment effects must be well characterized if experiment conclusions are to be applied to other aerosol systems. To aid in this characterization, a computer model of coagulation and Brownian diffusion in a closed container has been developed. This model, written in the C programming language and running on an Apple Macintosh computer, indicates the degree of spatial non-uniformity to be expected due to containment effects, as well as the rate at which the non-uniformities develop for a variety of initial aerosol particle sizes.

AN EXPERIMENT TO INVESTIGATE FULLERENE PRODUCTION UNDER REDUCED GRAVITY

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The proposed research will investigate the formation of the carbon species known as fullerenes and represented by C_{60} and C_{70}, in an electric arc in inert gas atmospheres while under reduced gravity/microgravity conditions. The rationale for carrying out such research in a reduced gravity/microgravity environment is that convection is very significant when the process occurs at normal gravity. Being able to alter the degree of convection that is a consequence of gravity by doing experiments involving free fall drops, aircraft flight trajectories, and space flight should give insight into the process by which fullerenes are formed and may assist in improving the efficiency of fullerene production with a subsequent reduction in cost of this now expensive material. Fullerenes have demonstrated interesting potential as 3-dimensional high-temperature superconductors, encapsulation species, new bases for organic chemistry, etc. Exploration of the fusion of fullerene production with microgravity techniques is exploration at the frontier of materials science.

Appendix D

GGSF Strawman Experiment Summaries

May, 1993

The Gas-Grain Simulation Facility (GGSF) Strawman Experiments summarized in this section were derived in part from a portion of the Candidate Experiments defined in the 1987 Gas-Grain Simulation Facility Workshop held in Sunnyvale, California on August 31–September 1, 1987. They are also derived from a requirements survey conducted by both Ames Research Center and TRW in the fall of 1991, and from new experiments which were suggested following the GGSF Science Workshop held in Las Vegas, Nevada on May 4–6, 1992.

Information contained in a corresponding detailed database (GGSF Experiment Information Database) on these experiments [14] was used for preliminary definition of the technical requirements for the GGSF and for a precursory facility concept design conducted by TRW during Phase A of Project development.

Not all experiments suggested to date are represented herein. The candidate experiments outlined here do not represent in any manner a selection or pre-selection of GGSF flight experiments. Flight experiments will be solicited at an appropriate future date by NASA Research Announcement (NRA) or Announcement of Opportunity (AO), and subjected to scientific peer review and mission compatibility reviews. The science to be accommodated by the GGSF is formally defined in a Level 1 Science and Technical Requirements Document at NASA Headquarters Life Sciences Flight Branch (SBF).

To meet future hardware development objectives, the GGSF Project may, as required, remove or add any candidate experiment to the database and subject the Strawman Experiments and associated requirements to peer review.

Experiment Number 1

Experiment Title:	**Low Velocity Collisions Between Fragile Aggregates**

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Abstract:
The earliest stage of accumulation of solid bodies in the solar nebula probably involved low-velocity (< 100 cm/sec) collisions of aggregates of submicron grains that were held together by weak interparticle forces (van der Waals or electrostatic). Relative velocities were induced by turbulence in the gas and/or systematic settling toward the plane of the nebula and depended on particle size, density, structure (e.g., fractal properties), and nebular properties. In order to understand the time scale for planetesimal formation, its efficiency (fraction of available material incorporated into macroscopic bodies), and evolution of the disk's opacity, the conditions leading to collisional aggregation or erosion/disruption must be determined as a function of particle size, velocity, composition and physical state.

Objectives:
To determine velocity regimes for coagulation and disruption of aggregates and determine size distributions in the latter regime.

Need for Microgravity:
Aggregates will be very fragile and cannot be manipulated in 1 g. Stresses induced by gravity would also affect collisional outcomes.

Procedures:
1. Form grains in situ if not brought from Earth.
2. Manufacture aggregates from grains by a) Brownian aggregation or, b) select and levitate an aggregate on the order of 100 μm formed by Brownian aggregation and shoot other aggregates at it to form larger aggregates up to about 1 cm.
3. Select and position two aggregates.
4. Measure properties (mass, density, fractal dimension). Image from several directions.
5. Accelerate the particles under observation.
6. Observe and record impact.
7. Clean chamber.

Experiment Number 2

Experiment Title: **Low Energy Grain Interaction/ Solid Surface Tension**

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Abstract:
Small solid particles corresponding to crystal forms of general interest are positioned for low-velocity encounters (≤ mm/sec) possibly using laser impulse or acoustic methods. Encounters are studied by high-speed photography to look for dynamics of the encounter, initial particle contact, and readjustment of contact surfaces to minimum (lower) energy configurations. Photometers are used to detect emission (fluorescence) resulting from contact and readjustment. Weakly bonded particles are monitored while UV photon absorption and third particle impacts cause excitation, rearrangement or dissociation. In addition to addressing some questions in basic physics, this experiment also has direct application to the study of particle sedimentation and coagulation in planetary atmospheres.

Objectives:
The experiment explores the physics of coalescence for solid, angular particles, studies slow processes (surface contact readjustment) which may result from activation-requiring processes, and characterizes third-particle and photon impulse dissociation. Particle charge will also be measured and sometimes modified prior to collision to study the effect on the above processes.

Need for Microgravity:
Microgravity is required to reduce disturbing forces (e.g., gravitationally induced drag) in order to study low-energy reconfiguration processes and the dynamics of subsequent impacts and photon absorption. Particles would also fall out of any reasonably sized chamber during course of experiments in 1 g.

Procedures:
1. Insert a particle into the chamber.
2. Determine charge by observing drift in E-field and possibly alter the charge (±) by TBD means (e.g., photoionization to increase + charge).
3. Insert second particle and repeat step 2; then position particles near each other (by laser pulse or acoustic methods).
4. Allow a controlled low-velocity encounter to occur.
5. Monitor the trajectory and subsequent readjustment of the particles using high-speed photography. Monitor light emission due to particle contact and readjustment.
6. Shine UV light on particles and observe the effect on particle readjustment.
7. Introduce third particle, allow low-velocity collision and again monitor results (lower priority).

Experiment Number 3

Experiment Title:	**Cloud Forming Experiment**
Contact:	Jim Hudson
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Abstract:
A water cloud is formed in an expansion chamber after the aerosol has been well characterized for its cloud forming ability. We do not know how rapidly droplets grow at small sizes (condensation coefficient) and this determines how many droplets form. Various aerosols would be used and attempts would be made to "poison" the droplets (reduce the growth rate). This work has direct applications to our understanding of planetary cloud formation.

Objectives:
Determine the condensation coefficient and see if it can be varied. Investigate the polydispersity of the cloud droplet spectrum. Investigate incorporation of insoluble particles into drops.

Need for Microgravity:
Microgravity, in concert with precise wall temperature control, is required to minimize convection, settling and wall condensation.

Procedures:
1. Produce and shape the aerosol (monodisperse or other).
2. Characterize aerosol and transfer to chamber.
3. Moisten air to known humidity.
4. Expand at specific rate and detect droplets; repeat compression and expansion with and without more nuclei, as well as with and without the same droplets removed.
5. Vary aerosol nuclei.
6. Mix in other air with or without other aerosols.
7. To minimize convection and wall condensation, control wall temperature precisely as latent heat of condensation is released.

Experiment Number 4

Experiment Title:	**Planetary Ring Particle Dynamics**
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Abstract:
The dynamics of planetary ring structure are strongly dependent on the energy losses in low-velocity collisions of ring particles. Examples include dispersion velocities (which control ring thickness), and the dampening of a variety of wave structures. Energy losses in low-velocity ring particles are characterized by a parameter called the coefficient of restitution. The objectives of this experiment are 1), to study the coefficient of restitution in collisions of planetary ring particles as a function of impact parameter, particle composition, relative sizes, surface texture, spin, temperature, etc. and 2), to study their transfer of linear to angular momentum.

Objectives:
Conduct low-velocity collisions of simulated planetary rings particles in a variety of configurations and environments.

Need for Microgravity:
Microgravity is required because; a) relative impact velocities are so low (10^{-4} to 10 cm/s) that particles would fall out of any reasonably sized chamber in 1 g; b) pendulum systems in 1 g are too massive to accommodate smaller samples and are very restrictive on ranges of motion; and c) the study of momentum transfer from linear to rotational cannot be performed adequately in 1 g.

Procedures:
1. Transport "ice balls" up and perhaps coat with soft frost in chamber.
2. Suspend one well characterized particle in a chamber or set up an ice coated target wall.
3. Fire a second particle at the first (or at wall) at low velocities; use a pendulum for very low velocities.
4. Record the motions of the particle(s) (both in translation and rotation) before, during and after the collision.
5. Particle characteristics (size, shape, composition, texture, temperature) must be completely described before and after each collision.

Experiment Number 5

Experiment Title: **Aggregation of Fine Geological Particulates in Planetary Atmospheres**

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Abstract:
Fine particles are injected into planetary atmospheres (and also around solar system bodies without atmospheres) by meteorite impacts, volcanic eruptions and aeolian activity. These particles are electrostatically charged and tend to aggregate. The rate and extent of aggregation determines sedimentation rates and thus the time of atmospheric residence and the geographical distribution of material. Residence time is relevant to hypotheses concerning nuclear winter scenarios, species extinction due to climatic change, climatic change in itself, the potential hazards of volcanic eruptions and the distribution of volcanic products, the duration of (e.g., Martian) dust storms, and the distribution of loess.

Objectives:
To determine growth rates, sizes, composition, and other properties of aggregates as a function of time, initial particle size, particle charges, atmospheric composition, the mode of particle comminution, etc.

Need for Microgravity:
Microgravity is needed because sedimentation in 1 g acts too rapidly to allow growth potential of aggregates.

Procedures:
1. Establish initial chamber conditions (N2 at 1 bar, 294 K, 0% humidity).
2. Measure total charge on dust sample before introduction to chamber.
3. Introduce dust into evacuated chamber with gas jet and then add gas as needed to adjust pressure (also try introducing gas first and dust second).
4. Allow aggregation to occur.
5. Monitor the following as a function of time during the aggregation process: particle size distribution of aggregates; ambient conditions (T,P,g, humidity); wall deposition; aggregate shapes using video microscopy; extinction properties of dust cloud using continuous spectrum source (IR to UV) coupled to a monochrometer (measure extinction vs. wavelength with photodetector(s) 180° from source).
6. Repeat each experiment for at least a total of 3 runs with the same conditions.
7. Vary dust composition, initial dust size, concentration, and mode of comminution for total of ~ 400 runs.
8. As a variation (a) perform the above in Earth analog atmosphere (air), and (b) perform in Mars analog environment (CO_2, 221 K with possible vulcanism to 366 K).

Experiment Number 7

Experiment Title: **Optical Properties of Low-Temperature Cloud Crystals**

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Telephone:	415-604-6538	602-621-6969

Abstract:
In the atmosphere of the outer planets, clouds are formed when gases with a range of partial pressures precipitate out and form ice crystals. Spacecraft observations have led to the derivation of optical single-scattering properties for these particles, but their physical properties (composition, shape, size) remain undetermined. Ground-based laboratory measurements in progress will catalog the properties of ice crystals grown under a variety of temperature and pressure conditions. However, due to the effect of gravity, particles grown slowly under low saturation conditions will fall out before reaching the desired sizes. A low-temperature chamber containing thermal diffusion plates with cylindrical windows is proposed with the goal of photographing and measuring the optical properties of ice crystals grown slowly under the low saturation conditions which more realistically simulate the Jovian atmospheres.

Objectives:
Determine the crystal habits of ices (NH_3, CH_4, CO_2 and other ices and impurities) grown at low temperatures and measure their single-scattering optical properties (phase, polarization properties) as a functions of size and shape.

Need for Microgravity:
Microgravity is needed because at low temperatures vapor pressures of these materials are quite low. The time required to grow loads of these ices at low degrees of supersaturation exceeds fall times in a reasonable sized chamber at 1 g. It is difficult to measure scattering from a single small crystal and levitation at 1 g does not solve the problem.

Procedures:
1. Admit prepared gas with and without solid aerosol impurities (S, P,...)
2. Lower temperature on diffusion chamber plates to achieve condensation/crystallization.
3. Monitor optical depth and turn on diagnostics when cloud achieves desired optical thickness.
4. Record crystal growth on video.
5. Measure the scattering properties of resultant crystals over 180° including intensity and polarization as a function of wavelength and angle.
6. Collect crystals on bottom of chamber (electrostatic attraction) and photograph.
7. Vary conditions and repeat experiment.

Experiment Number 8

Experiment Title: **Ice Scavenging and Aggregation: Optical and Thermal IR Absorption and Scattering Properties**

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Abstract:
The experiment involves 3 parts. The first part consists of H_2O ice crystal generation in a thermal diffusion chamber with/without various aerosols or water drops as a basis. The crystal growth will be observed with video in conjunction with a microscope of variable magnification which will provide both broad pictures of crystal growth as well as high magnification and resolution for a more detailed study. In the second part, crystal growth will be stopped and the crystals will be transferred to a second chamber, or section of same chamber, for optical and thermal IR absorption studies. Transmission and scattering of solar/thermal IR radiation will be measured. Absorption and scattering of the dispersed ice particles will be measured (possibly in an E-field to simulate more realistic nonrandom crystal orientations) by multiple and single path optics as appropriate in the solar and thermal IR parts of the spectrum. FTIR measurements will also be taken at this time. This will have direct application to the role of cirrus clouds in the global climate. The third part of the experiment will take place in the thermal diffusion chamber. As ice crystals are formed, the scavenging of aerosols by the ice crystals will be investigated and diffusiophoretic velocities will be deduced from concentration measurements.

Objectives:
Observe crystal growth under various conditions using video microscopy; measure optical and thermal IR and scattering properties of grown crystals; observe scavenging of aerosols by ice crystals.

Need for Microgravity:
These experiments can't be done in 1 g for crystals > a few tens of microns since they would fall out too quickly. Also in microgravity crystal growth, ice aggregation mechanics, and the scavenging of aerosols can be studied and controlled with minimization of gravity induced convection and settling ventilation.

Procedures:
1. Nucleate and grow ice crystals with or without aerosol in thermal diffusion chamber (e.g., generate water drop spray, silver iodide smoke) at different temperatures and pressures.
2. Observe crystal growth with video (end part 1).
3. Stop growth and transfer to optical observation chamber or section.
4. Perform optical, thermal, IR and FTIR studies while aggregation occurs.
5. Desirable to collect, store and return crystals to Earth for analysis (end part 2).
6. Again nucleate and grow ice crystals in thermal diffusion chamber with aerosol as above, and observe scavenging of aerosols (e.g., generate carbon soot, NaCl smoke or spray) by ice crystals (end part 3).
7. Collect and dehydrate crystals and store respective scavenged aerosols for return to Earth.

Experiment Number 9

Experiment Title: **Synthesis of Tholins in Microgravity and Measurements of Their Optical Properties**

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Cornell University
Ithaca, NY 14853

Telephone: 607-255-3934

Abstract:
We have already produced and measured the optical properties of varieties of tholin films resulting from irradiation of charged particles and ions on the reactant gases. All our tholin experiments were done at low pressures (~ 2 mbar) and at 1 g, in which case the particles form, quickly go to the wall of the container and deposit there as a film. We do not know the shape and scattering properties of the haze particles in suspension, but only of the bulk properties of the film they form. In this proposed microgravity experiment, there is sufficient time for growth and suspension so that photometric properties can be measured and directly compared with measurements of Titan's haze by Voyager and from Earth. Later experiments could study Uranian and Neptunian tholin. To back out optical constants, particle size distributions and photometric behavior must be determined. Particle size distributions will be determined from scattering studies using a He-Ne laser. Photometric behavior will be studied with a spectrometer in the UV-VIS-NIR (0.2-2.5 μm) range and chemical changes occurring in the tholin particles due to the growth of the particles by irradiation of ions and charged particles or by coagulation of the particles, will be studied with an FTIR spectrometer (2-25 μm). Thus, for the first time, band formations as a function of particle size growth will be observed. Chamber substrates with deposited tholin films will be returned to Earth. The deduced translation between computed and measured values will then help provide the index of refraction for the entire wavelength region from soft x-ray to 1 mm (Earth tholin film studies will be used to fill in the gaps below 0.2 μm and above 25 μm).

Objectives:
The ultimate goals of the experiment are to determine the optical constraints n and k (real and imaginary parts of the index of refraction) for Titan's upper atmosphere tholins and their scattering properties and signatures.

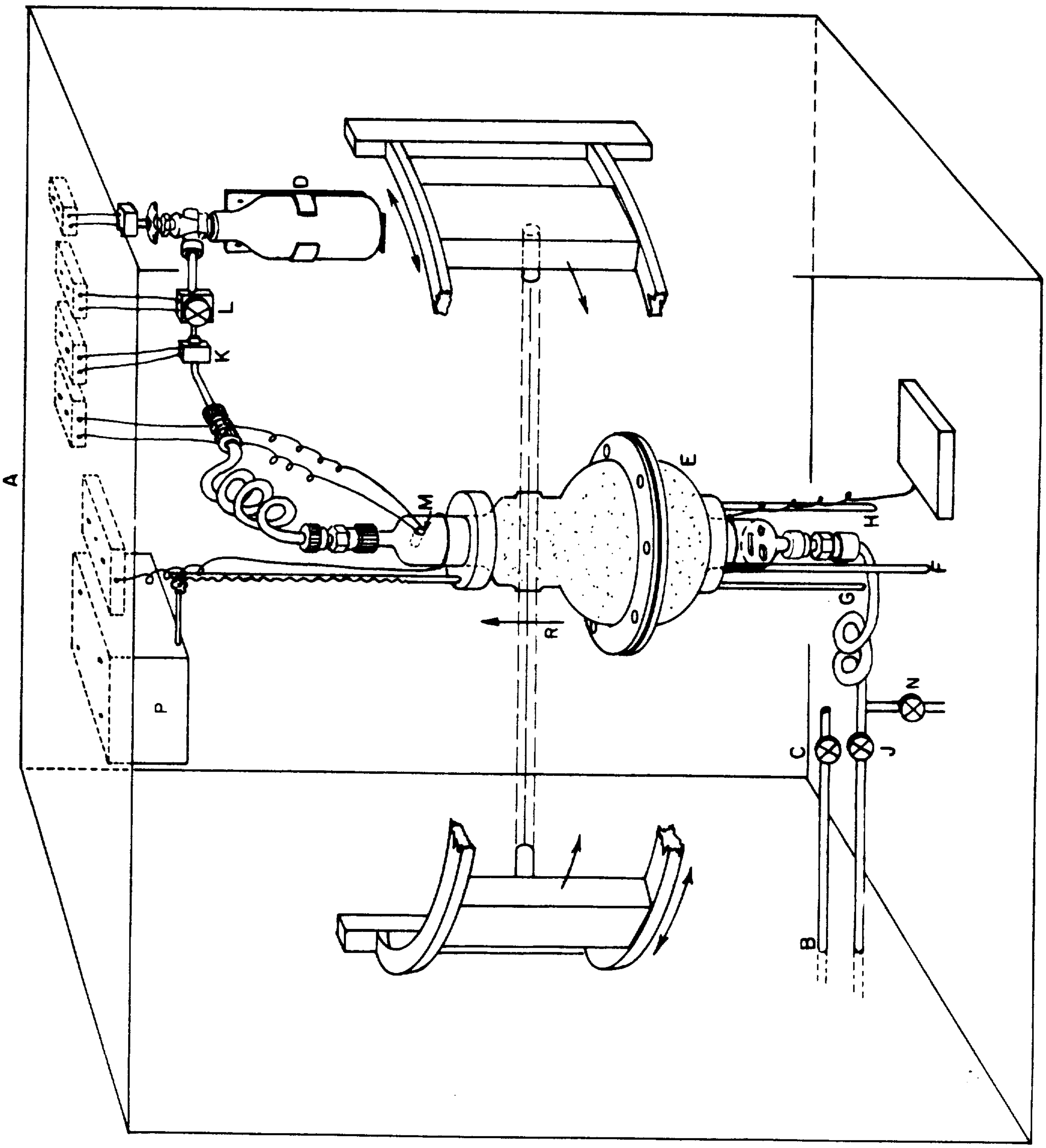
Need for Microgravity:
Microgravity offers a unique opportunity to allow the necessary particle suspension time for growth and the prevention of wall loss which have precluded the above observations on Earth.

Procedures: (see author's attached sketch)

1. Establish same initial conditions (Titan's upper atmosphere) in quartz reaction vessel and in larger outer chamber surrounding it (see author's attached sketch).
2. Open top half of reaction vessel by remote control and turn on (0.2 - 2.5μm) spectrometer (rail mounted) and take background reading on reactant gases before tholin is formed. Measurements are taken in a small angle (0 to 10° in 0.5° steps) to simulate Earth-based observations and in a larger angle regime (0 to 180° in 10° steps) for a more general study.
3. Close reaction vessel and initiate low flow rate (0.05 cc/s) of reactant gases at 2 mbar. Fill outer chamber with same gases at 1 bar (tholin will only form in low pressure and not in the outer chamber).
4. Align spectrometer and detector at 180° so that light passes through spectrosil windows in upper part of reaction vessel. Align FTIR (rail mounted) at right angles to spectrometer

so that IR (2 - 25µn) baseline transmission readings can be taken through KBr windows in the upper reaction vessel.

5. RF discharge is induced, tholins grow, and flow provides replacement gases for further formation and replacement of any vented tholin. When transmission reaches 70% of baseline, RF discharge and flow are stopped. This process may take about 45 minutes.
6. He-Ne laser system simultaneously tracks the size spectrum during tholin growth.
7. Pressure outside the reaction vessel is now reduced to 2 mbar to match inside pressure and upper half is lifted. Photometric data is taken corresponding to all angles in step 2) (takes 3 or 4 minutes) giving essentially containerless measurements. Repeat for 50% and 30 % transmission. Prepared substrates will also have been placed and removed from the reaction vessel in each case for analysis of the tholin films on Earth.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Experiment Number 10

Experiment Title:	**Metallic Behavior of Aggregates**
Contact:	Denise P. Traver
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Abstract:
The transition of atomic/molecular properties to bulk material properties is of interest and utility. Proposed here is a plan to study the onset and evolution of metallic behavior by monitoring the changes in the UV-visible absorption spectrum as a function of aggregate size, composition and fractal dimension. The optical spectrum of bimetallic aggregates (grown in a low-g environment) will reveal the beginning of metallic character by the collapse of single-component absorption bands and the emergence of collective plasmon frequency absorptions. Size distributions of ensembles of aggregates will be measured by light scattering techniques. In addition, single particle measurements can reveal the dependence of metallic properties on fractal dimension (aggregate geometry).

Objectives:
To study the onset of metallic behavior of molecular aggregates: (1) as a function of cluster size and composition (particle ensemble measurement) and (2) as a function of fractal dimension (single particle measurement).

Need for Microgravity:
Microgravity provides extended levitation times and the possibility of tenuous low-density, high volume aggregate structures which are gravitationally unstable on Earth.

Procedures:
1. Condensation of bimetallic aggregates from a vapor (or expansion through a nozzle).
2. Measurement of UV-visible absorption spectrum.
3. Simultaneous measurement of the size distribution via laser light scattering.

Experiment Number 11

Experiment Title: **Investigations of Organic Compound Synthesis on Surfaces of Growing Particles**

Contact: Verne Oberbeck
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Telephone: 415-604-5496

Abstract:
This experiment is to determine the role played in chemical evolution by cometary entry and post-entry atmospheric processes acting on fragmentation and vaporization products. The science questions are: Could amino acids and other complex organic compounds necessary for the origin of life have been synthesized during coalescence of particles of cometary origin; does particle growth preserve synthesis products formed by high temperature entry and UV irradiation; and, do the particles formed play a role in polymerization of amino acids?

Objectives:
Generate organic and silicate aerosols. Monitor growth of coalescing particle with a size spectrum analyzer and perform high precision laser chromatography (HPLC) analysis of bulk aerosol samples upon return to Earth. Determine if, with realistic cometary impact fluxes, the coalescence of particles could be an important process for chemical evolution.

Need for Microgravity:
Chemical reactions require days, and to allow growth of large particles long cloud/particle suspension times are required. For 1.0 µm-radius particles, in one week, displacements due to gravitational sedimentation on Earth (in STP air) would be on the order of 100 m, but in microgravity (10^{-6} g) only on the order of 1 mm. Thus a very small chamber size is sufficient for an experiment on an Earth-orbital platform, but an impractically large experimental chamber is required on Earth.

Procedures:
1. Establish initial chamber conditions which simulate one of the various altitudes in early Earth's atmosphere.
2. Generate a multicomponent aerosol cloud inside the chamber. The aerosol will be composed of simple organic compounds found in comets, such as H_2O, silicates and/or complex organics such as amino acids.
3. Monitor the aerosol cloud size spectrum as a function of time using an aerosol size spectrum analyzer.
4. Collect cloud particles at end of experiment run, store and return for HPLC analysis on Earth.
5. Parameters such as pressure, temperature, aerosol composition and concentration, and rate of adding material (if any) during experiment should be varied and experiment repeated. The duration of the entire experiment is on the order of four weeks.
6. Relate results to aerosol growth models to test hypothesis of role of particle growth in chemical evolution.
7. As a variation: high concentrations of amino acids in water drops can be introduced into the chamber with aerosol generators. The aerosol cloud will be exposed to UV light and subjected to cycles of wetting and drying. The cloud particles will be collected and returned to Earth for chemical analysis.

Experiment Number 12

Experiment Title: **Crystallization of Protein Crystal-Growth Inhibitors**

Contact: Jim Raymond
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Abstract:
Crystal growth inhibition may be an important biological process. It has been shown to occur in humans in the prevention of growth of kidney stones, in some fish in prevention growth of ice and may be important in bone formation, tooth decay and precipitation of uric acid (gout). Some of the most important inhibitors are proteins; determining their mechanism requires a knowledge of their conformation which is best obtained from x-ray diffraction of large crystals. Fish antifreeze is a good choice for a model system because of (1), their stability and (2), their interaction with crystal substrate (ice) without the need for moderators. Attempts to grow antifreeze crystals so far have been only marginally successful. Microgravity, which has been shown to promote the growth of some protein crystals, may be beneficial for the growth of antifreeze crystals.

Objectives:
Produce macroscopic crystals (~1 mm in radius) of antifreeze glycoprotein (AFGP) that are suitable for X-ray diffraction analysis. Ultimate goal is to determine conformation of these molecules and clarify mechanism of binding of protein crystal growth inhibitors to their crystal substrates.

Need for Microgravity:
AFGP molecules are very weakly bound to AFGP crystal; convection due to density gradients at (a) drop surface and (b) crystal front interferes with crystal growth and could be removed in a microgravity environment. Edge effects that interfere with crystal growth on Earth can be removed by working with suspended drops.

Procedures:
1. Chamber at 277 K, 80% relative humidity.
2. Inject droplet(s) of saturated protein solution, approx. 3 mm dia. with syringe.
3. Maintain position for 12 - 24 hours until drop has dried to crystal or glass using occasional electrostatic or acoustic levitation.
4. Monitor growth with visual (microscopic) inspection by crew; take microscopic pictures and transmit to Earth.
5. Perform possible light scattering measurements during growth.
6. Remove sample and return to Earth for microscopic inspection and x-ray diffraction.

Experiment Number 13

Experiment Title:	**Dipolar Grain Coagulation and Orientation**
Contact:	Friedemann Freund
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Abstract:
Studies on MgO (as a model substance) and olivine (as realistic interstellar dust component) have shown that dipolar defects contained in the mineral matrix, due to C-bearing complexes, can undergo ferroelectric ordering. If grains are single domains with a resulting dipole moment, they will (a) agglomerate in a filamentary fashion and (b) orient in an externally applied electric field. Grains which move at a given velocity through an interstellar/intergalactic magnetic field will orient. Starlight shining through such dust clouds will become polarized. Experiments with MgO and CaO smoke under microgravity conditions are proposed.

Objectives:
The primary goal is to understand: (a) process of grain alignment in dust clouds and polarization of starlight in line of sight and; (b) dimensionality of agglomeration of dust grains. The distant goal of this work is to understand the role of C/CO/CO_2 in cosmic dust and the possible single domain ferroelectric nature of minute silicate dust grains. If confirmed, filamentary alignment of dust grain agglomerates represents an approach to understanding the polarization of starlight (in line of sight) shining through dust clouds (application to the Martian upper atmosphere is of particular interest), Also, fractal formation of dipolar grains will be different from "isotropic" fractals.

Need for Microgravity:
Dipole-dipole interactions between suspended grains are weak and relatively short-ranged. Large filamentary aggregates are too fragile to be studied in 1 g and would collapse under their own weight. Microgravity is essential to carry out a successful experiment.

Procedures:
1. Establish initial chamber conditions (gas composition, T, P, E-field).
2. Produce smoke in chamber. Simple oxides such as MgO and CaO can be produced in situ by burning metal rods or ribbons in the chamber.
3. Allow agglomeration of grains in an externally applied electric field, with and without soft UV.
4. Monitor particle spectrum size and shape with time by measuring light scattering intensity and polarization.
5. Also monitor orientation of elongated (filamentary) agglomerates in electric field using above diagnostics.
6. Several experiments will be performed using different samples and/or gases during smoke production. Each experiment run will take 4 to 5 hours, but actual active time is only 10 to 30 minutes.

Experiment Number 14

Experiment Title: **Titan Atmospheric Aerosol Simulation**

Contact:
Address:

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Christopher McKay
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415-604-6864

Abstract:
The objective of this experiment is to simulate the formation of organic haze particles in Titan's atmosphere. These experiments would build on the extensive experience obtained already in ground-based laboratories in simulating the production of organic materials in Titan-like atmospheres. The microgravity environment would allow for the extension of these experiments. Specifically, the formation of organic particles, the nature of their growth, their optical properties and their physical and chemical properties can be investigated. This experiment is timely in light of upcoming missions, in particular the Cassini Mission, to study Titan.

Objectives:
To study growth of organic particles modeling the aerosols on Titan; to measure the optical properties (indices of refraction) of the particles; to study the chemical composition of the particles.

Need for Microgravity:
Microgravity is needed to enable formation of organic particles entirely in the gas phase, without being influenced/determined by the presence of walls. This will allow growth of particles under conditions more appropriate for Titan's atmosphere.

Procedures:
1. Evacuate chamber - test vacuum and gas handling system.
2. Run calibration tests - test laser scatterometer, levitation systems.
3. Verify operational status - test data to be evaluated by ground experimenters.
4. Fill chamber with gas mixture. Measure pressure and let equilibrate.
5. Measure baseline scattering.
6. Irradiate gas mixture with UV light to form tholin particles. Particles begin to aggregate so that mixture of single particles and aggregates develops.
7. Turn off UV periodically (e.g., 1 hr. on, 1 hr. off) to study effect of aggregation with and without tholin formation.
8. Measure scattered light intensity and possibly polarization as functions of wavelength, angle and time. From this particle size and index of refraction will be deduced. May need levitation to fix position of one or some particles.
9. Retrieve particle(s) on collection plate, store and return to Earth for further analysis.
10. Repeat varying initial conditions.

Experiment Number 15

Experiment Title: **Surface Condensation and Annealing of Chondritic Dust**

Contact: Frans Rietmeijer and Ian MacKinnon
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University of New Mexico
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Abstract:
Sequential interaction of metal-bearing vapors with a refractory core to simulate chemically zoned interstellar dust (IS) or solar nebula grains. Subsequent thermal annealing might result in an onion-type, chemically complex grain to a multiphase mineralogical assemblage. Annealing is envisioned in a sequentially lowered thermal regime which would simulate decreasing temperature during stellar ejection or cooling of a solar nebula. Variations in gas phase compositions (C:H:O-ratios) are introduced to simulate realistic extraterrestrial gas-phase environments.

Objectives:
Simulate gas-dust reaction textures in extraterrestrial materials especially carbonaceous chondrite meteorites and interplanetary or cosmic dust . These materials give rise to new nanocomposites which may be precursors to important cosmochemical and astrophysical processes. Study surface energy related effects that occur. Obtain information on chemical composition and textures of these analogs.

Need for Microgravity:
Surface reactions are probably dominating parameters. The experiment requires availability of all surface area and no interactions with container walls. Adequate suspension times are required.

Procedures:
1. Form refractory oxide cores in chamber (crucible evaporator).
2. Inject, sequentially, metal-bearing gases as a function of decreased condensation temperature.
3. Annealing of core-mantle grains. Steps 2 and 3 will be dictated by presumed diffusion times. Injection times between introduction of subsequent gaseous species increases as experiment progresses.
4. Collect experimental products for electron microbeam analysis on earth.

Experiment Number 16

Experiment Title: **Studies of Fractal Particles**

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Telephone:	301-286-9467	505-667-7363

Abstract:
Very low density fractal aggregates are formed on a small (~ 1 µm) scale in 1 g in "soot" aerosols and as colloids in solution. In zero-g such fractal particles may grow to much larger dimensions and may play important roles in circumstellar and interstellar environments as well as in the early solar nebula. We would like to measure the coagulation coefficient of a variety of bare silicates, ice-coated silicates, organic-refractory coated silicates and organic-refractory grains. Once the particles have begun to form we would like to measure the scattering and extinction properties of the aggregate as a function of the fractal dimension from as far in the UV to as far in the IR as is possible. These measurements would be taken following growth from the initial cloud until a single fractal particle was formed. We would then use the acoustic levitation system to break up the grain and measure its cohesive strength, allow it to reaggregate and coat the grain with ices. We would then measure the strength of the ice coated grains after the optical scattering and extinction were measured. Again, let the grain coagulate with its ice coating; irradiate it to get a refractory organic coating; measure its optical properties and its cohesive strength. Then use the acoustic system to measure its strength one final time.

Objectives:
Understanding the radiative and dynamic characteristics of a variety of fractal materials which may have astrophysical significance.

Need for Microgravity:
The required suspension times for growth to centimeter size fractals is not possible in 1 g. Furthermore, fractal particles of centimeter dimensions would be unstable in a 1 g field and would tend to collapse.

Procedures:
1. Establish initial chamber conditions (a predominantly Ar with H_2 atmosphere at room temperature and pressure).
2. Use crucible evaporator to introduce silicate or metal vapor into the chamber and allow particles to nucleate.
3. As the particles coagulate, from a cloud to a final single aggregate, perform the following as functions of time:
   a) measure light scattering and extinction properties;
   b) monitor fractal structure of particles by taking video "snapshots"; and
   c) collect samples, fix (by TBD method) and store for return to Earth for SEM analysis.
4. Repeat for two additional runs. The duration of each run is on the order of hours to days.
5. Perform the above experiment again, but introduce oxygen into the chamber after fractal particles have grown to a single particle by coagulation. Then take scattering measurements. Repeat two additional times.
6. Again repeat the initial experiment, but first introduce oxygen into the chamber just after particles have nucleated from the vapor. Repeat two additional times.
7. Repeat the above with four different vapors.
   Experiment Variations

1. Same experiment(s) as above. Once final single fractal has formed, break up with acoustic levitation and allow to reaggregate. Repeat this many times.
2. Variation (1), but admit various gases (TBD) to chamber and irradiate particle to allow organic coatings to form prior to breaking apart.
3. Variation (1), but admit ethane, propane , or other gases to chamber and lower temperature (~ liquid nitrogen temperatures) to ice-coat fractal particle prior to breaking it apart.
4. Variation (3) but admit methane, ammonia, or other gases and lower temperature (< 77 K).
5. Use larger fractals as condensation nuclei for water drops. Perform scattering and extinction measurements.

Experiment Number 17

Experiment Title: **Optical Properties of Particles and Clusters**

Contact: Lou Allamandola
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MS 245-6
Moffett Field, CA 94035
Telephone: 415-604-6890

Abstract:
The emission (radiative) of particles in various environments such as circumstellar shells, planetary nebulae, protostellar disks, reflection nebulae, HI/HII interfaces has, up to now, only been modeled or measured by making very crude, often demonstrably incorrect, assumptions. The purpose of this experiment is to suspend clusters of molecules and particles of various sizes and shapes (as well as of different composition) and excite them with visible and UV light, monitoring their optical properties in the red, near infrared, and IR spectral ranges. Particular emphasis should be placed on IR as this is where the bulk of the emission from the galaxy falls and where little is understood on a microscopic scale.

Objectives:
To measure optical properties (emissions, luminescence, scattering, absorption) of clusters of molecules and of clouds of as well as single microparticles (single particles is a wish which may not be achievable). To be able to understand how radiative energy is converted from the VIS/UV to the red, near Infrared and IR in various environments.

Need for Microgravity:
Microgravity allows the suspension of particles and clusters for a long enough time to accumulate enough signal to measure emission spectra of free species. Particles can't be singly suspended in the laboratory on Earth. Molecular clusters to my knowledge can't be prepared in enough quantity for a long enough time to accumulate a measurable signal from them.

Procedures:
1. Evacuate chamber or introduce inert gas.
2. Generate clusters or particles (eventually grow ices on these particles).
3. Position clusters or particle(s) in the chamber.
4. Monitor emissions continuously.
5. Warm or excite the particles with UV/VIS radiation and continue to monitor emissions. Luminescent (fluorescent and phosphorescent) frequencies will appear.
6. Perform scattering and absorption measurements using UV/VIS/IR source.
7. Samples will be small and soluble. Collect after experiment and dispose of.

Experiment Number 18

Experiment Title: **Effect of Convection on Particle Deposition and Coagulation**

Contact: Won-Kyu Rhim
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MS 183-401
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Pasadena, CA 91109
Telephone: 818-354-2925

Abstract:
Aerosols of liquid and solid microspheres of various sizes at various concentrations are placed in a chamber with forced convective flow and are studied to examine the effect of the convection on particle coagulation and wall deposition.

Objectives:
Study effect of convection on deposition and coagulation of micron and larger size particles.

Need for Microgravity:
Microgravity allows well characterized convection w/o gravity-induced convection and helps avoid gravitational deposition.

Procedures:
1. Establish initial chamber conditions.
2. Generate aerosols; liquid aerosol generator for liquids; TBD generator for solids.
3. Monitor size spectrum of aerosol using an optical size spectrum analyzer (also provides concentrations).
4. Aerosol generation provides uncontrolled turbulence. Use feedback to establish proper concentration while coagulation and deposition are taking place. The goal is to reach steady state, however, this may not be achievable and an approximation may have to be accepted. Continue to monitor until sufficient statistics of the state achieved are obtained.
5. Now turn off aerosol generator, apply controlled convection, and observe transient decay.
6. Evacuate chamber and repeat with different particle size and/or concentration.

Experiment Number 21

Experiment Title:	**Study of Smoke Agglomerates**
Contact:	George Mulholland
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Telephone:	(301)975–6695

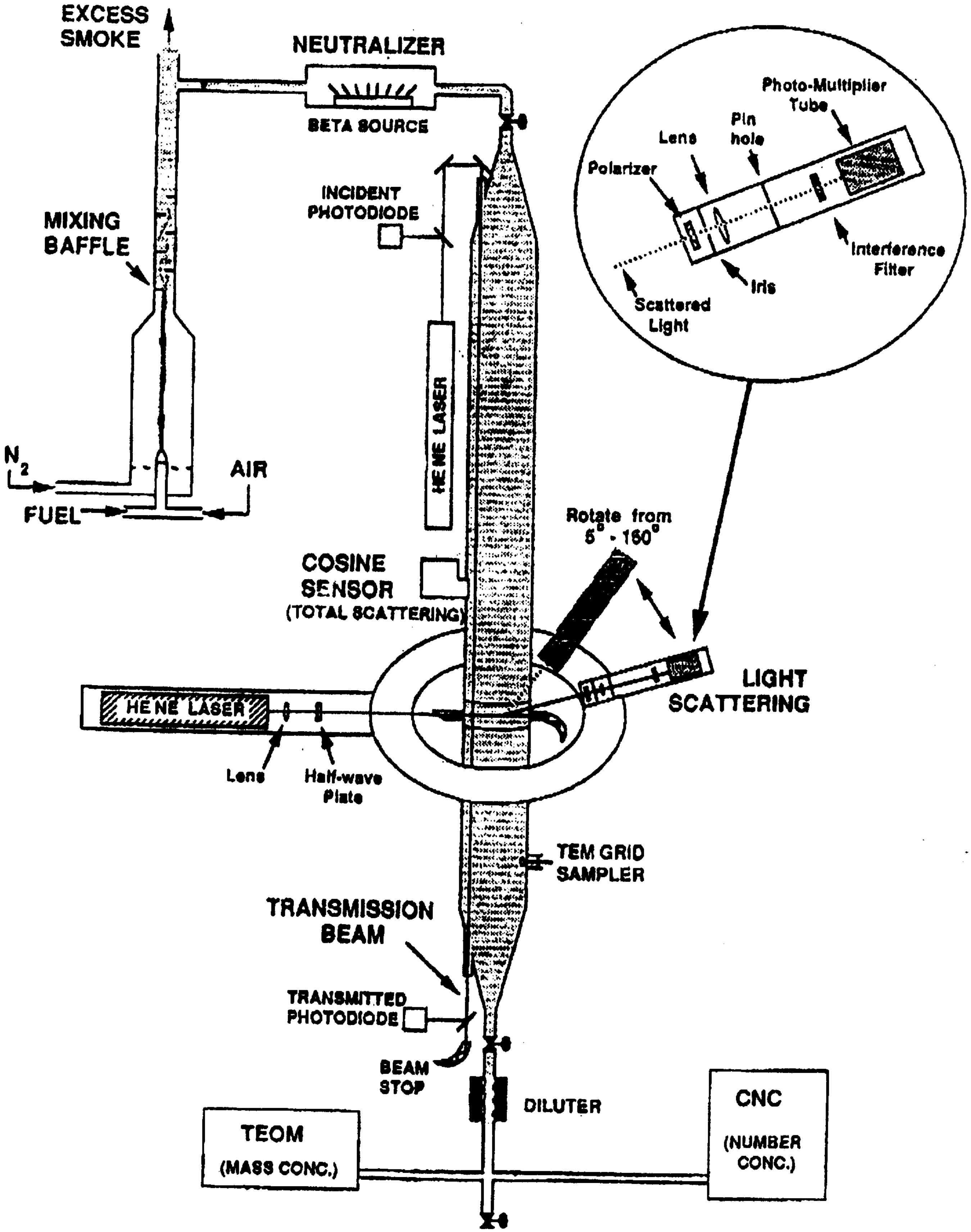
Abstract:
Low density smoke agglomerates are formed during flaming combustion of carbon containing fuels. Laboratory studies of the growth and properties of smoke agglomerates at 1 g are limited to agglomerates less than about 5 µm because of sedimentation. We would like to generate small smoke agglomerates from a flame and to study the growth of large smoke agglomerates from cluster-cluster collisions. The growth would be studied in a transmission-cell reciprocal-nephelometer allowing the measurements of the optical properties of the agglomerates as they grow. Optical properties as a function of agglomerate size, fractal dimension, and radius of gyration versus time and growth kinetics (agglomeration coefficients) will be determined. The effect of the formation of large agglomerates on the optical properties of the smoke is of great importance to the prediction of the climatic impact of a global smoke cloud. The experiments would provide a clear cut test of the applicability of fractal optics to smoke agglomerates.

Objectives:
To understand the optical and dynamic characteristics of large smoke agglomerates as they grow from small agglomerates through cluster-cluster collisions.

Need for Microgravity:
Microgravity will allow the growth of larger agglomerates that would settle out at 1 g.

Procedures: (see author's attached sketch)

1. Generate smoke agglomerates using a laminar flame. Mixing baffles give uniform concentration since agglomerate sizes will vary. Allow smoke to burn for minute or two to reach steady state before opening inlet valve on chamber.
2. Pass smoke through neutralizer (doesn't neutralize but equalized ± charge distribution which has an effect on the early stages of agglomeration) on way to chamber.
3. Fill transmission-cell reciprocal-nephelometer chamber with smoke agglomerates (open chamber valve and burn for 2 or 3 minutes and close).
4. Perform measurements of light extinction, total scattering (using Cosine Sensor) and angle dependent scattering (using He-Ne laser) as the agglomerates grow by a factor of 1000.
5. Measure mass concentration using TEOM (Tapered Element Oscillating Microbalance).
6. Measure number concentration using CNC (Condensation Nucleus Counter); but will commercial versions function in microgravity?
7. Withdraw samples at selected times on TEM (Transmission Electron Microscopy) Grid Sampler. These will be returned to Earth for analysis.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Polarizer
Interference Filter
Iris
Scattered Light
Rotate from 5° - 160°
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LIGHT SCATTERING
HE NE LASER
Lens
Half-wave Plate
TEM GRID SAMPLER
TRANSMISSION BEAM
TRANSMITTED PHOTODIODE
BEAM STOP
DILUTER
TEOM (MASS CONC.)
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Experiment Number 22

Experiment Title: **Effects of NO_x on Airborne Microbial Survival**

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Abstract:
Bacteria are found in a variety of habitats including the air. The viability of airborne bacteria appears to depend on atmospheric constituents including particulates, NO_x, relative humidity, and ultraviolet radiation. Increases in relative humidity or particulates appear to enhance the survival of airborne bacteria. Increased levels of NO_x, or ultraviolet radiation seem to decrease the survival of certain airborne bacteria. There are numerous scientific questions that arise from aerobiology studies conducted on the Earth's atmosphere. The experiment proposed here addresses the question "What is the interaction between airborne bacteria and NO_x ?" This interaction between bacteria and NO_x is important in predicting not only what types of bacteria are best fit for survival in the atmosphere, but also how bacteria can affect air quality. To investigate this interaction known numbers of a variety of denitrifying and non-denitrifying bacteria obtained from the American Type Culture Collection will be cultured and aerosolized while in log phase growth. The bacterial aerosols will be exposed to 0 to 5 ppm of NO or NO_2 for a week to two weeks. Periodically during the experiment and at the end of the experiment, the bacteria will be collected and the number of survivors determined.

Objectives:
Because NO_x is an intermediate in denitrification the two primary goals of the experiment are to determine if: 1) airborne denitrifying bacteria remain viable in the presence of gaseous NO_x longer than other microbes; and 2) denitrifying bacteria change the NO_x level in the atmosphere through their metabolism.

Need for Microgravity:
Because Earth's gravity would prevent a bacterial aerosol from being suspended for a week or more, the only way to conduct such an experiment is in micro-gravity.

Procedures:
1. Known numbers of a variety of bacteria obtained from the American Type Culture Collection will be cultured and aerosolized while in log-phase growth.
2. To meet the objectives, aerosolized denitrifying and non-denitrifying bacteria will be exposed to 0 to 5 ppm of NO, or NO_2, for a week or more depending on their generation times.
3. Growth, if any, will be periodically monitored by collecting and analyzing small aliquots of the aerosol during the experiment. The method involves collecting the aerosol on a filter, incubating the organisms in a growth medium and counting the number of organisms in the developed colonies to compute the number of organisms per unit volume of aerosol. Collection efficiency is calibrated with an aerosol having a known number of organisms per unit volume.
4. At the end of the experiment the bacteria will be collected and the number of survivors determined.
5. Attached to the top of the chamber will be the gas inlet. To determine the absolute gas concentration in the chamber a gas sampling port will be incorporated into the chamber.
6. Gas samples will be collected periodically during the course of the experiment and analyzed gas chromatographically.

Experiment Number 23

Experiment Title: **Infrared Emissivity of Extraterrestrial Particles**

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Abstract:
Study the emission characteristics of individual grains of material gathered from the space environment. A broad spectrum of particle classes could be studied with emphasis going to interstellar and interplanetary dust grains gathered while in orbit.

Objectives:
To measure the infrared emission from these rare individual grains and compare their properties with those deduced from classical astronomy.

Need for Microgravity:
Grains gathered while in orbit will be studied while in orbit and not contaminated by containers and other terrestrial gases which could modify their properties. Levitation is required in order to decouple grain lattice from any other material objects.

Procedures:
1. Capture particle using a space collection device (on substrate).
2. Introduce particle to chamber (pressure < 10^{-12} bar, wall temperature < 40 K (best if 4 K)).
3. Levitate particle.
4. Heat particle with emission lamp and measure spectral emittance (IR detectors) vs. wavelength and time (particle temperature controlled 4-1000 K).
5. Monitor heating source power, pressure, temperature of walls, temperature of particles and gas composition.
6. Repeat 3 & 4 for other particles on same substrate.
7. Capture particle.
8. Withdraw and archive for return to Earth for analysis.

Experiment Number 24

Experiment Title: **Radiation-Induced Rotation of Interplanetary Dust Particles Under Microgravity**

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Melbourne, FL 32901-2714

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Abstract:
The primary purpose of this experiment is to study the dynamics of rotation of interplanetary particles under the influence of solar radiation. This spin mechanism is known as the "Windmill Rotation", which is caused by the angular momentum generated from the uneven scattering of photons by surface irregularities of the particles. This type of rotation has an effective moment arm caused by the random nature of the particles' surface irregularities, presently estimated to be of the order of 5 x 10-4 times the maximum dimension of the particle. The interesting part of this rotation is that it leads to rotational bursting when the stress from rotation overcomes the internal cohesion of the particle. Repeated rotational bursting of the fragments lead to smaller and smaller sized particles which will be expelled from the solar system by the action of solar radiation pressure exceeding the solar gravitational attraction. Evidence for the expelled particles were observed by Earth orbiting satellites and they are called "ß meteroids." There are many important implications for rotational bursting of dust in areas such as the solar system (interplanetary dust, comet tails, etc.), interstellar dust, reflection Nebulae, dust shell stars, etc.

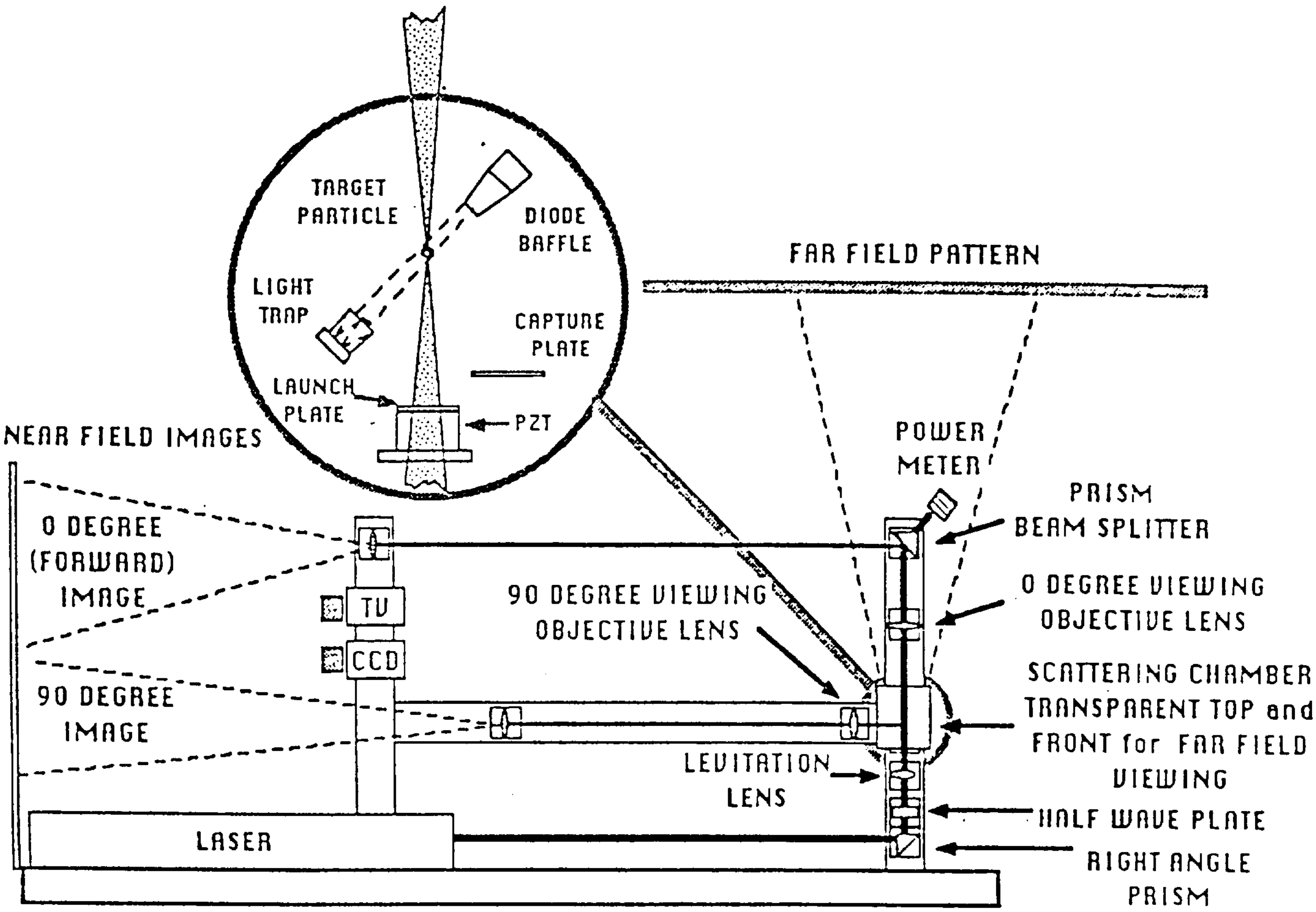
Objectives:
To determine the rotation rate and rotation acceleration induced by laser light and magnitude of the effective moment arm of the rotation of injected particles, which are a mixture of man-made and collected interplanetary particles from Earth's atmosphere. Some particles may burst depending on the strength of the laser beam and the duration of the light exposure, among other things.

Need for Microgravity:
The spin mechanism that we intend to study cannot take place except in a space or space-like environment. The laser energy that would be required to perform this experiment on real or simulated interplanetary particles in 1 g would modify or destroy the structure of the particles through heating. Microgravity and the vacuum of 10^{-9} to 10^{-10} bar will enable the particles to spin freely as they do in space with minimal friction or damping forces and without heat damage to the particles.

Procedures: (see author's attached sketch)

1. Create two antiparallel laser beams which, equipped with a servo system, will balance the linear momentum imparted by the beams on the particles and compensate for any undesired translational movement of any single particle selected. The antiparallel beams will create confinement as well as initiate the particles' rotation.
2. Create a vacuum of 10^{-9} to 10^{-10} bar, using a turbomolecular pump.
3. Turn on the video system and inject the particles into the glass chamber, while the laser beams are on.
4. Operate the scanning video camera and enable its movement via a rail structure around the chamber.
5. Record and transmit the TV photos to Earth in real time. At some point in time during the experiment some of the data will be stored on tape and returned to Earth later.

6. Digitize the images of selected particles which are stabilized and have exhibited windmill type rotation. This will be carried out with an onboard computer equipped with the necessary software.
7. Repeat the same procedures for new sets of particles. We may need up to five sets of particles during the entire experiment.



TARGET PARTICLE
DIODE BAFFLE
LIGHT TRAP
CAPTURE PLATE
LAUNCH PLATE
PZT
NEAR FIELD IMAGES
FAR FIELD PATTERN
POWER METER
PRISM BEAM SPLITTER
0 DEGREE (FORWARD) IMAGE
TV
CCD
90 DEGREE VIEWING OBJECTIVE LENS
0 DEGREE VIEWING OBJECTIVE LENS
SCATTERING CHAMBER TRANSPARENT TOP and FRONT for FAR FIELD VIEWING
90 DEGREE IMAGE
LEVITATION LENS
HALF WAVE PLATE
LASER
RIGHT ANGLE PRISM

Experiment Number 25

Experiment Title: **Dynamics and Evaporation of Clusters of Drops in Flows**

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Abstract:
Particles in vortical flows occur in a variety of atmospheric and industrial processes such as: the shear layer created by a volcanic eruption; the shear layer created by a stack discharge into the atmosphere; the shear layer of catastrophic fuel-pool fires; Martian dust-devils; tornadoes; centrifuges; the shear layer of air-injected fuel spray in a combustion chamber, etc.... The behavior of the particles in the flow controls the penetration of the volcanic plume into the atmosphere, the dispersion of the particles from the stack-plume, the local pressure on Mars or the efficiency of combustion. Models of drop dynamics in vortical flows show that the control parameters determining the dynamics and evaporation of the drops are different for dense and dilute collections of drops (i.e. high and low drop number density). Specific numerical predictions made for the dilute regime were corroborated by experimental results. However, the numerical predictions made for dense collections of drops, although agreeing with intuition, cannot be compared with experimental observations since for high drop number densities the medium is optically inaccessible thus prohibiting measurements.

Objectives:
Perform observations of the dynamics and evaporation of drops in the high particle number density regime, thereby obtaining a data base for comparison with numerical results.

Need for Microgravity:
The small size (20-40 μm radius), high particle number density regime which is optically inaccessible is equivalent to a large size (100-300 μm radius), low particle number density regime in terms of the particle interactions which determine the characteristics of the dense regime. Large size drops cannot be suspended in 1 g before the drops evaporate because of the settling effect. Estimates based upon characteristic lengths and times show that microgravity is the <u>only</u> environment suitable for such experiments.

Procedures:
1. Inject monosize drops in the chamber.
2. Induce a vortical motion by rotating a cylinder in the chamber (a rotor).
3. Allow effective entrainment (i.e. spiral motion of drops to develop).
4. Perform cold flow measurements(drops and gas are at the same temperature) by using photographic means.
5. Purge the chamber after the required time for observation.
6. Repeat each experiment for at least a total of 3 runs using the same initial conditions.
7. Vary initial drop size, initial drop density and initial gas velocities
8. Perform 1 and 2, except that in 2 warm gas is injected through the porous rotor, thus allowing now the study of evaporation.
9. Perform warm flow measurements (drops are initially colder than the gas) by using photographic means for drop size and trajectories. To measure temperature, pyrometry, a thermocouple array, or the acoustic sonar method will be used.
10. Investigate the same parametric regime for initial drop size, initial drop number density and initial gas velocities.
11. Vary the initial gas temperature.

Appendix E

The Gas-Grain Simulation Facility (GGSF) for Space Station Freedom: Design Concept

The following is a reprint of a paper presented in Washington, DC at the 1992 World Space Congress and the 43rd Congress of the International Astronautical Federation, August 28 – September 5, 1992. For permission to copy or republish, contact the International Astronautical Federation, 3-5, Rue Mario-Nikis, 75015 Paris, France. Its publication reference number is Paper # IAF-92-0950.

IAF-92-0950

THE GAS-GRAIN SIMULATION FACILITY (GGSF) FOR SPACE STATION FREEDOM: DESIGN CONCEPT

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Abstract

The GGSF is specifically designed to accommodate μ-g experiments that investigate long-term effects and interactions between submicron to centimeter size particles. The paper introduces the science disciplines and the type of experiments that are currently envisioned for the GGSF. The broad range of science and technology requirements are discussed, and the Space Station Freedom (SSF) accommodations and available utilities are reviewed. Based on the requirements and the available accommodations, a facility conceptual design is outlined. The required subsystems are listed, and the rationale and considerations that lead to the selected approach, delineated. The present GGSF concept is that of a modular facility system comprising a flight rack and an array of fully compatible and interchangeable subsystems that are designed to meet a diverse set of science requirements. The modularity allows for future upgrade of various subsystems as technology evolves and for introduction of new modules to accommodate new or different experiments. These features are essential for a facility that is expected to be in service on board the SSF for 10 years or more.

Introduction

The GGSF is a multidisciplinary facility, scheduled to fly on board the Space Station Freedom (SSF) in late 1998, designed specifically to study interactions between small grains or particles and their long-term behavior and characteristics. GGSF will be designed to investigate various physical mechanisms or processes and will allow the simulation of distinct natural systems of interest to several science disciplines as listed in Table 1. This diverse set of experiments objectives was suggested by the results of a workshop conducted by NASA Ames Research Center (ARC) in 1987 and published as a NASA conference publication[1].

The need for a μ-g environment stems from several reasons. First, the forces that are investigated, such as van der Waals, coulomb, surface tension, etc. would be totally obscured or dominated by the Earth's gravity. Second, large particles cannot be suspended and investigated for a long enough period to adequately simulate natural phenomena. Third, buoyancy-driven forces are reduced significantly. Finally, unstable and fragile objects such as fractal particles can be investigated in the μ-g environment.

The GGSF is expected to remain on orbit for at least 10 years to accommodate a vast range of experiments. More than 20 strawman experiments have been identified as candidates for the GGSF, reflecting a broad interest within the science community. A brief description of several typical experiments is given below.

Low-velocity collisions between fragile aggregates. The earlier stage of accumulation of solid bodies in the solar nebula involved low-velocity collisions of aggregates of submicron dust grains held together by weak interparticle forces. In order to understand the time scale of planetesimal formation and its efficiency, the conditions leading to collisional aggregation or erosion/disruption must be determined as a function of particle size, velocity, composition, and physical state. The objective of the experiment would be to determine the velocity regime for coagulation and disruption of aggregates.

Cloud-forming experiments. Many aspects of atmospheric and planetary cloud formation are not well understood and experiments involving crystals and droplets are planned. Micro-gravity studies of the properties of cirrus cloud crystals will help clarify their role in the balance of the earth's atmospheric radiation budget and hopefully answer question on global warming. The rate of growth of droplets at small sizes and how certain parameters affect this growth will also be studied. Various aerosols will be used to form droplets under controlled conditions and condensation (growth) coefficient will be determined.

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[3]NASA Project Scientist.

[4]NASA Project Manager.

Table 1. Science Drivers for the GGSF

Science disciplines	Exobiology, planetary science, atmospheric science, biology, chemistry, physics, and astrophysics
Systems to be simulated	Planetary rings, atmospheric clouds, interstellar clouds, planetary atmospheres, Martian dust storms, stellar nebulae
Processes to be investigated	Aggregation, nucleation, accretion, coagulation, evaporation, condensation, collisions, fractal growth, freezing and evaporation, scavenging, UV photolysis, polymerization, longevity of bacteria, crystal growth

Optical properties of low-temperature cloud crystals. The outer planets are covered by clouds which play a key role in many fundamental aspects of these massive atmospheres including temperature structures, radiation budget, and atmospheric dynamics. Knowledge of the microphysical properties of the cloud particles is necessary in order to analyze the role they play. The measurement of optical properties of particles such as crystals of ammonia and methane ice will help in the interpretation of observations of these planets.

Titan atmosphere aerosol simulation. Atmospheric aerosols are important in determining the chemical and radiative properties of planetary atmospheres and hence in determining, for example, atmospheric thermal profiles and planetary surface temperatures. Micro-gravity will extend the ground-based studies by allowing for a longer period of growth and hence larger sizes in studies of organic particle formation and growth, and in measurements of optical, physical and chemical properties.

Effects of NOx on airborne microbial survival. The fate of airborne is a central concern of aerobiology. Do they remain viable and do they multiply? The answers may be critical to the health and safety of a spacecraft crew since microbes may affect air quality significantly in the micro-gravity environment, allowing potential pathogens to spread more readily than in 1-g. These issues, including the effect of NOx on bacterial viability, will be investigated in this experiment.

Science and Technical (S&T) Requirements

The GGSF is required to simulate within a facility chamber various operating conditions to meet the requirements of these diverse science disciplines. These conditions cover a broad range of parameters and are listed in Table 2.

The experiments that investigate the outer planets' atmosphere and interstellar dust require the extremely low temperatures, while experiments interested in the inner planets are interested in the high temperatures. The planetary experiments are also the source for the various

Table 2. Summary of Science and Technical Requirements

Chamber pressure, bar	From 10^{-10} to 3 bars, with a desire to reach 11
Chamber temperature, K	From 10 to 1,200 K, with a desire to reach 4 K
Chamber volume	From 1 cm^3 to several hundred liters, various geometries
Particulate matter type	Liquid aerosols, solid-powder dispersions, soots from combustion, high-temperature condensates (nucleation of metal and silicate vapors), low-temperature condensates (ices of water, ammonia, methane, or CO_2), a single liquid droplet, a single or a few particles, in situ generated particulates by UV or RF radiation, or by electrical discharge
Particulate size range, µm	from 10 nm to 3 cm
Particulates concentration	a single particle to 10^{10} particles per cm^3
Gases required	air, N_2, H_2, He, Ar, O_2, Xe, H_2O, CO_2, CO, NH3, CH4, and more experiment specific gases
Diagnostics required	In-line optical systems and off-line sample analyses, including measurements of the grain size distribution, the number density (concentration), optical properties such as index of refraction, emission and absorption spectra, imaging, measurement of the grain's strength, mass, density, electrostatic charge, and geometry, collisions parameters including particle kinematic parameters before and after the collision
Experiment duration	From a few seconds, for collision experiments, to weeks, for the biology experiments

gases and ices required. The collision experiments that are interested in planetary rings generated the requirements for the large particle sizes. The large chamber volume is a requirements of the biology experiments.

SSF Environment and Accommodations

The GGSF will utilize one international standard payload rack (ISPR) and to be installed in the SSF U.S. laboratory module. Two modes of operations are anticipated. In the early stages, during the man-tended configuration (MTC), the SSF will be visited by the shuttle every 90 to 180 days and the GGSF will operate in an automated or remote-control mode. Later during the permanently manned configuration (PMC), the astronauts will be available to assist with the facility and experiment operations.

The physical accommodations of the rack[2,3] are shown in Table 3. The level of gravitational acceleration and vibrations on board is expected to be in the range of 10^{-5}g, for frequencies below 0.1 Hz, and 10^{-3}g, for frequencies 10 Hz and above.

GGSF Conceptual Design

The broad range of the S&T requirements specified for the GGSF, exemplify the need for the design to a ***modular facility system***. This system will be composed of a flight rack in which a specific hardware configuration is installed for a set of experiments that can take advantage of the hardware commonality. In addition, the system will consist of an array of fully compatible, interchangeable, assemblies that can be brought to SSF and installed in the flight rack to meet various other experiment requirements. The replaced assemblies will be returned to Earth for maintenance as necessary. The interchangeable assemblies include various facility chamber configurations, sample generators, diagnostics modules, experiment-specific equipment modules, electronic accessory plug-in units, and consumables such as gas cylinders. The other subsystems making up the GGSF include all the maintenance and housekeeping subsystems such as command and control electronics, data acquisition, power distribution, waste management, and other interfaces indicated in Table 3. A block diagram of the facility and its interfaces with the SSF through the U.S. module is given in Figure 1. This approach will also allow for the system upgrade as technology advances over the lifetime of the GGSF.

Table 3. International Standard Payload Rack Features

Physical dimensions	2 side-by-side 19" racks per EIA RS-310-C Maximum depth 75 cm, height 164 cm, width 93 cm
Payload volume	~1.13 m^3 out of 1.55 m^3 total
Miscellaneous	Fire suppression system using CO_2
Configuration	4-post or 6-post racks available
Weight capacity	4-post rack weighs ~ 58.5 kg, supports 700 kg 6-post rack weighs ~ 68.2 kg, supports 700 kg Structural augmentation is required for payloads > 400 kg for stiffness.
Construction	Composite (graphite/epoxy)
Electrical Power	Up to 3 or 6 kW depending on the location
GN2 Supply	Through a 3/8-inch line at a pressure between 90 and 110 psia (0.621 to 0.759 MPa)
Vacuum exhaust	Waste management under strict control of allowable waste gases and contaminants
Vacuum vent	Provide vacuum down to about 10^{-6} bar
Avionics air	About 1kW cooling capacity
Cooling water	Two loops of cooling water, one at a low temperature
Communications	Communications interfaces via a MIL-STD-1553 and an FDDI buses

In addition to the S&T requirements, the facility design is driven by general considerations such as safety-related issues, human engineering factors, and facility lifetime.

In considering the wide range of experiment requirements, several facility constraints become apparent. These can be divided into constraints imposed by the laws of physics such as:

- For experiments performed in vacuum, the sedimentation time at 10^{-5}g for all particle sizes is of the order between 30 to 50 seconds, depending on the chamber size
- For experiments not conducted in vacuum, the very small particles (e.g., submicron) are lost to the chamber wall by Brownian motion induced diffusion in a relatively short time. The very large particles (e.g., 100s μm) are also lost in a relatively short time by sedimentation.

Constraints imposed by the SSF are:

- Prohibition of cryogenic fluids on board the U.S. module limits the low temperature that can be achieved with mechanical cryocoolers to about 40 K for a small chamber and about 150 to 200 K for a large chamber
- Very stringent requirements that limit the dumping overboard of certain gases that are used by the GGSF, creating the need to install a complex waste management subsystem.

The launch of the GGSF is expected to take place in stages. First, a core facility will be launched and installed on board the SSF. This core GGSF will have a broad range, but not all, of the capabilities.

Additional hardware and enhancement will be launched and installed at later times to accommodate additional experiments.

Facility Chamber

Numerous requirements drive the chamber design considerations and approach. Because many of the requirements create conflicting engineering considerations, no single chamber can meet all the S&T requirements. At least four chambers are required to meet all the experiment conditions. The chambers are listed in Table 4. A fifth chamber that has no active temperature control may be useful for initial experiments over a limited range of the parameter space. A typical chamber design is shown in Figure 2.

The chamber is of a double-walled, vacuum-jacketed construction to reduce the thermal conductive heat loads. Radiation shielding between the two chamber shells is used to reduce radiative heat loads. Each chamber is equipped with a number of ports, interfaces, and windows that also provide conductive and radiative paths for thermal heat loads. The ports include CCD camera windows (2), illumination windows for the CCD cameras (2), diagnostic light port (2), sample generator port (2), gas vent and fill (1), power feedthrough (1), sensor data feedthrough (1), cryocooler interface (1), and internal mounting provisions for additional optical detectors or experiment-specific hardware. Each chamber is designed with a large removable lid for both shells for maintenance and clean up. The rack can accommodate only one chamber at a time.

Table 4. GGSF Chambers

Purpose	Volume, liters	Pressure, bar	Temperature K
Large volume	67	10^{-6} - 1	150 - 400
Low temperature	4.2	10^{-6} - 3	60 - 400
High temperature	8.2	10^{-6} - 1	300 - 1,200
High vacuum	4.2	10^{-10} - 1	60 - 400

Cooling of the chamber is accomplished with a mechanical cryocooler. The cooler must have sufficient cooling capacity, minimum power consumption, and small size and weight. The baseline design has selected a water-cooled cryocooler with 15-watt heat rejection capacity at 77 K with about 700 watts electrical power.

Because of the thermal loads, the limited cooling capacity, and the size of the chamber, the large-volume chamber cannot be cooled to below about 150 K, and even that temperature is reached with a cool-down period of several hours. In order to reach the lower temperatures, a smaller chamber was selected, as shown in Table 4.

In order to reach pressure below that supplied by the SSF vacuum line, a special chamber equipped with an integral high-vacuum pump is designed. The pump is directly mounted to the chamber to maximize the conductance. Either a turbomolecular or a getter-type pump may be appropriate. The SSF vacuum line serves for roughing the high-vacuum pump.

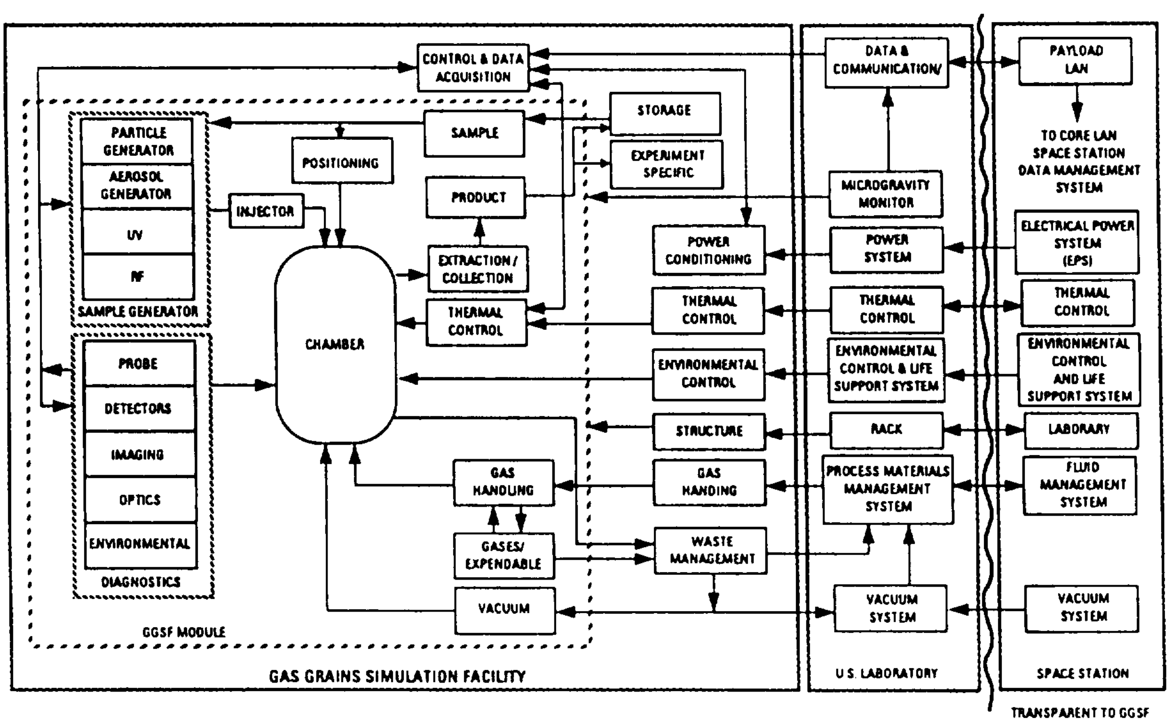

Figure 1. GGFS Block Diagram and SSF Interfaces

Sample generation

A summary of the sample generation requirement is given in Table 5, in which the list is divided according to the type of sample. Here again, as with the chamber, no single technique can meet all the requirements. The challenge is to identify techniques that would minimize the number and type of generators required to fulfill the broadest range of the requirements.

Generation techniques in each of the categories listed in Table 5 were reviewed and several concepts selected based on their operating principle, which include insensitivity to gravity, reliability, range of applicability (i.e., particle sizes, size distribution, etc.). For those experiments that require vacuum, the sample generator cannot use a carrier gas. Similarly, some experiments that require a precise composition of the chamber atmosphere cannot tolerate the introduction of the sample with a carrier gas. Other issues related to the introduction of the sample into the chamber relate to the uniformity of the initial distribution throughout the volume and to the velocity at which the particles are introduces. Vacuum experiments cannot tolerate any velocity, since all particles introduced with an initial velocity would impact the wall. The sample generation techniques that were reviewed are listed in Table 6. Laboratory testing of several techniques are underway and a final selection will be made on the basis of the test results and verifications tests to be conducted using ground-based low-gravity facilities such as NASA's KC-135 or the 0-g Facility.

Each of the sample generators is to be designed with standard mechanical and electrical interfaces so that each generator can be mounted into any of the chambers and any of the two sample generation ports on each chamber. This approach allows for future growth and development of new generation techniques.

Diagnostics

The diagnostics are divided into the following categories. In-line systems that perform measurements on samples in the chamber, including extinction measurements, angular and spectral scattering, diffraction, and imaging. Off-line systems that remove samples from the chamber for analysis, including various particle counters (condensation nuclei counter, diffusion battery, electrical mobility analyzer, etc.) and filters and impactors for mechanically capturing the samples. The third category of diagnostics includes the environmental diagnostics that monitor the pressure, temperature, humidity, gas composition, and g-level. All diagnostic systems are to be fully interchangeable and compatible with all chambers, but not all the techniques can be used in a given facility configuration.

In-line diagnostics. These include nonintrusive optical diagnostics that utilize a transmitted light beam and determine various sample characteristics on the basis of the interaction between the incident light and the particles. The transmitted bean may be either a monochromatic laser light, or, interchangeably, a broadband source (e.g., tungsten filament lamp) for FTIR-type characterization. The broadband source can also be sent through a filter wheel to select a specific spectral range, or through a monochromator for a higher resolution in the selection of the transmitted light. Other sources available, include continuum or line emitters in the UV, visible, and IR.

The specific types of in-line measurements include extinction, angular scattering with detectors placed at various angular positions from 0 to 180°, polarization, and diffraction. These measurements allow the determination of the particle size distribution, their number density, and various optical properties.

Finally, imaging using two CCD cameras can view the experiment sample at 90° to each other, allowing the

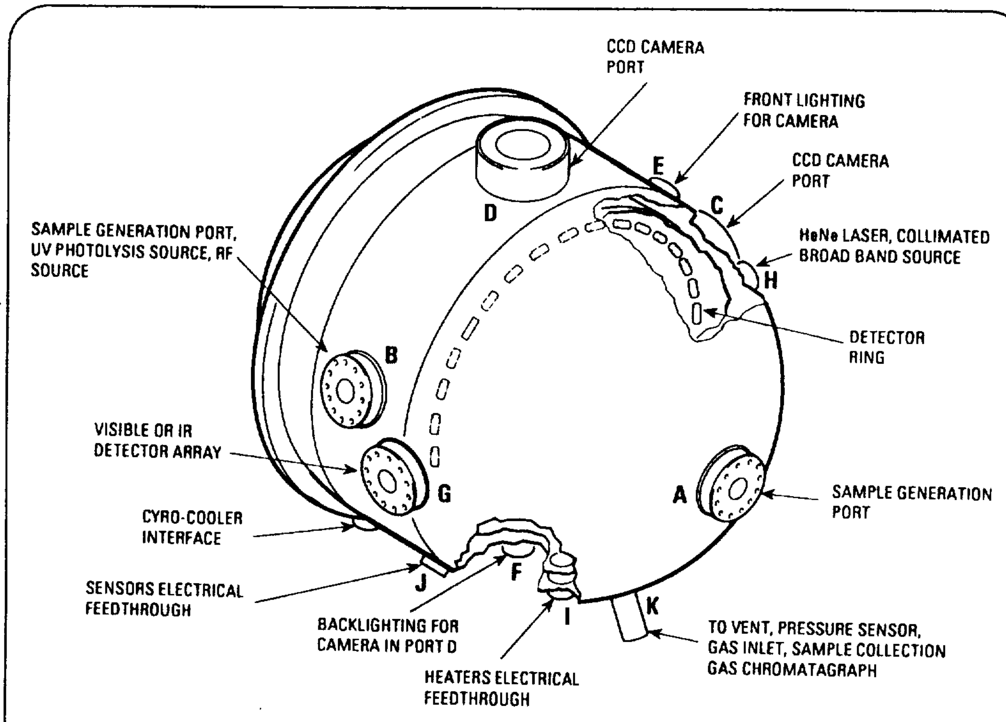

Figure 2. GGSF Typical Chamber

Table 5. Summary of Sample Generation Requirements

Sample Type	Materials	Size, μm	Concentration no./cc	Pressure, bar (desired)
Solid particles	Silicate grain, salt, quartz, basalt, carbon, olivine, pyroxene, alumina, TiO_2, MgO, microspheres	0.01 - 1000	1 - 10^8	10^{-10} - 1 (10)
Liquid aerosols	Organic solutions, microbes in nutrient solution, others TBD	0.1 - 50	300 - 10^5	0.05 - 1 (11)
Single particle/ drop	Silicates and ice coated silicates, tholin, ices of NH_3, CO_2,	1 - 10^4	One or two only	10^{-6} - 1
Soot and smoke	Hydrocarbon combustion soot, MgO, PAH	0.0005 - 10	1 - 10^8	10^{-10} - 1
In situ samples	From gas mixtures using RF, UV, E-discharge, E-fields	0.005 - 10	10^5 - 10^8	0 - 1
Low-temperature condensation and nucleation	Ices of H_2O, CO_2, CH_4, NH_3	0.01 - 2,000	1 - 10^8	10^{-6} - 3
High-temperature condensation	Bimetallic elements, metal-bearing gases, metals, silicates	0.01 - 100	10^6- 10^{11}	10^{-6} - 1

measurements of the velocity vector of moving particles. RS-170 video output may be recorded on an analog VCR, or the signal may be sent directly to a frame grabber for digitization. The cameras can be driven at the standard RS-170 mode or at a faster data rate up to 100 frames per second. This data rate is sufficient to resolve the particle kinematic parameters for the collision experiments. A zoom/macro lens allows to adjust the field of view and resolution of the cameras. The system will be able to operate with various high-resolution CCD arrays, if necessary.

The option of overall cloud behavior imaging is provided by various lighting schemes, including front- or back-lighting the cloud and introduction of a light sheet created from the laser beam via anamorphic optics.

Off-line diagnostics. For those experiments in which the particle size and concentration falls outside the region of operations for in-line methods (e.g., extinction below ~5% or above ~95%) off-line methods are provided. These include for the very small particles (down to 0.001 μm) a combination of an electrical mobility analyzer, diffusion battery, or a condensation nuclei counter. For the large particles, filters and impactors are available for capturing sample.

In considering the off-line diagnostics, experiments that operate in low pressure or vacuum may not be amenable to these techniques because of the difficulty of withdrawing a sample from the low-pressure environment in the chamber. Furthermore, in some cases the required flow rate and duration of flow into the diagnostic instrument is such that cannot be tolerated by the experiment. And finally,

Table 6. Sample Generation Techniques Considered for the GGSF

Solid Dispersion	Blast deagglomeration, exploding wire, fluidized bed feeder, aspiration feeder, auger feeder, atomization of hydrosols, atomization of dissolved solids
Liquid aerosol	"Spray can," squeeze bottle, pressure atomizers, electrostatic atomizers, thermal ejector (ink jet), various nebulizers, vibrating orifice, spinning disk
Hi temperature vapors	Radiation heating, electric arc, gas furnace, electric furnace
Soot generation	Diffusion flame, premixed fuel-rich pyrolysis
Single droplet	Syringe, thermal ejector (ink jet)
Single solid particle	Mechanical
In situ generation	UV radiation source, RF coil, super saturation and nucleation, heterogeneous nucleation

another issue to consider is the nonisokinetic sampling from the chamber.

Environmental diagnostics. Two types of pressure transducers are provided. An ionization gauge is used for the vacuum range and a conventional diaphragm with a bonded-strain-gauge-type transducer is used for the higher range. The selected technique must be insensitive to the gas composition or to the gravity so that gauges that measure pressure by detecting the thermal conductivity (and rely on free convection) of the surrounding gas (e.g., Pirani) are inappropriate.

The temperature is measured in the facility chamber and at several locations on the walls of the chamber using RTDs.

Gas composition is measured with a gas chromatograph (GC) that is connected directly to the facility chamber and to the gas mixing chamber. Humidity can be measured in the GC or with a solid-state relative-humidity sensor located in the gas mixing chamber.

g-level. The g-level monitoring could be done with the SAMS, an instrument developed by NASA/LeRC for the measurement of accelerations down to the 10^{-6}g along three axes.

Storage

A limited volume is defined within the GGSF for the storage of sample material pre- and post-test and for some of the interchangeable GGSF subsystems.

Gas handling and mixing

The gases for the various experiment mixture could be provided in two ways: premixed and pure gas cylinders. The premixed gases may be used to fill the chamber directly with the premixed composition. If new compositions are required or modifications to the initial composition is needed, then the pure gases are used. A mixing chamber equipped with a fan is available for preparing gas mixtures. The chamber is also equipped with pressure transducers that allow the filling of the chamber with the individual constituents according to their partial pressures.

The gas bottles are positioned on a pallet for easy removal and replenishment operations.

Waste management system

The function of the waste management subsystem is to clean up the experiment waste to a level compatible with the SSF waste and vent lines specifications. Particulate matter and toxic gases must be treated and removed from the effluents and any significant concentration cannot be dumped overboard.

The subsystem consists of a series of treatments as follows:

- Removal of particulates via a coarse and a fine mesh filters
- Gas scrubbing beds, including activated and impregnated charcoal for the removal of hydrocarbons, and basic gases, and other beds (e.g., LiOH) for the removal of acid gases
- Catalyst beds for the oxidation of H_2 and CO.

Additional treatment may be necessary for various experiments. The flow treatment system is packaged into a removable canister. The system may include a circulating fan to run the waste through the treatment several times until the desired level of cleanup is achieved. The removal of substances occurs via adsorption and chemical reaction, which in some cases is exothermic. In those cases, active cooling of the canister may be required, depending on the amount of waste products.

In addition to the plumbing and valving associated with the waste management subsystem, a monitoring system (e.g., pressure drop) is utilized for "health monitoring."

Electrical and electronics

The electrical and electronics subsystems consist of two general elements. The first element includes those components that are interchangeable and support/control other interchangeable hardware modules such as sample generators, various chambers, diagnostics units, etc. These elements contain local capability for control and data acquisition and may have the capability to digitize signals for noise reduction. The second element is "fixed" in the GGSF and provides communications and control, interface with the operator, interface to the U.S. laboratory and the utilities, and transmission of image and data to and receiving commands from the U.S. laboratory module or ground control (through the U.S. module). These elements include the display monitors, other user interfaces such as keyboard or touch panels, and the computer. An electrical block diagram is shown in Figure 3.

Electrical. The SSF provides 120 Vdc and the payload is responsible for power conditioning and distribution within the payload facility. The GGSF power management system consists of three converters as shown in Table 7.

The preliminary analysis indicates that both the primary and secondary converters will be rated for a maximum load of 750 watts and a steady-state average of 500 watts at a conversion efficiency of about 80 to 87%.

Electronics. Because of the longevity requirements of the GGSF, a **modular payload computer system** is planned. The rapid evolution in microprocessors is expected to continue to double the CPU speed every four to five years as in the past decade. Therefore, a CPU upgrade built-in capability is necessary. In addition, various types of I/O modules may be required for different experiments. For

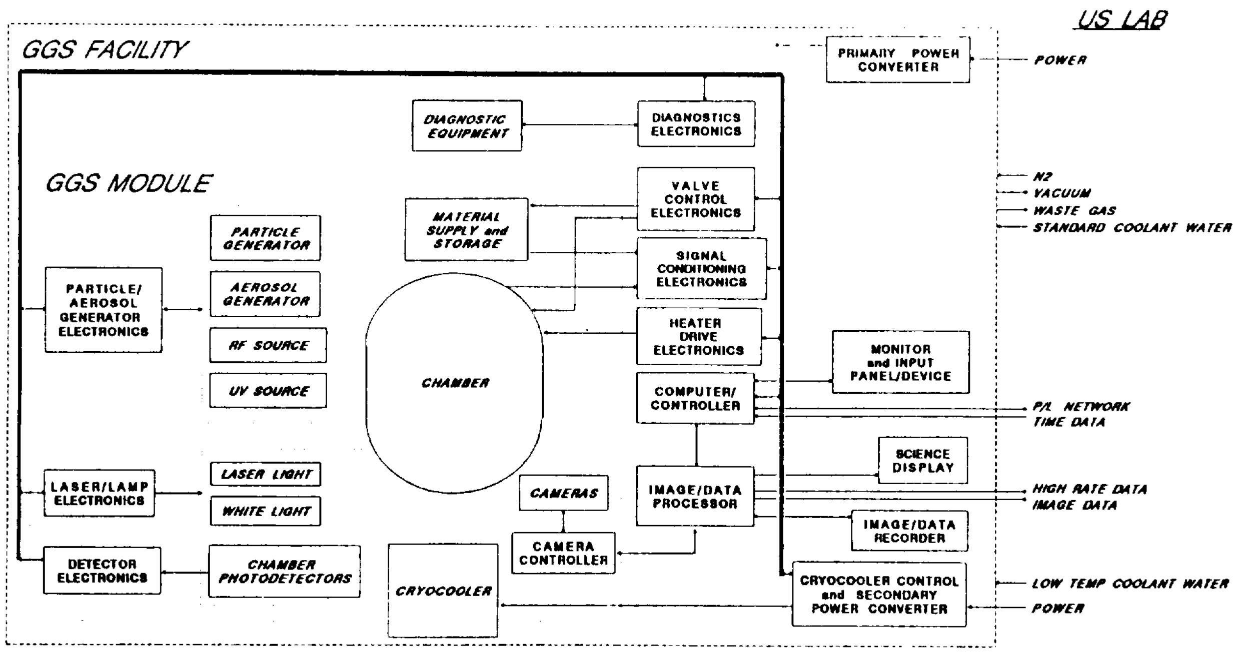

Figure 3. Electronics Block Diagram

instance, valve controllers, a frame grabber, thermocouple modules, preamplifiers, other A/D and D/A units, heater drivers, etc. These modules could be independent plug-in boards that are installed into a passive backplane or a card-cage configured system as required by the experiments.

The modular computer will provide communications capabilities via the MIL-STD-1553 and the FDDI buses via similar plug-in modules. For heavy computational loads a DSP module may be provided.

Table 7. GGSF Power Management

Output	Application
Converter 1, Primary Conversion form 120 Vdc to:	
115 Vac, 50/60 Hz	Use of "off-the-shelf" instrumentation and equipment
+28 Vdc	MIL-level relays, wide equipment selection, existing hardware design
+8 Vdc	To permit local regulation for logic supplies, etc.
±18 Vdc	To permit local regulation for amplifiers, signal processing circuits
Converter 2, Secondary Converter from 120 Vdc to:	
115 Vac, 60 Hz	For high-power applications, e.g., cryocooler
Filter	
120 Vdc	For low-level distribution to allow for presently

<u>Automation, robotic, and AI</u>

During MTC, the SSF will provide the most quiescent period of time while the shuttle is not docked. That time is ideal for those experiments that require a long duration quiescent environment. The down side of the MTC period is that the facility will require extensive automation for operating.

Various modes of GGSF operations have been defined and are listed below in order of increasing complexity level.

1. Manual or remote control: uses a man-in-the-loop (on board or via down/up link)
2. Open-loop operations: based on time sequencing or some trigger to start or stop certain operations
3. Simple closed-loop operations: utilizes simple sequencing or trigger to initiate certain operations and sensors with feedback control for other activities.
4. Action based on a simple quantitative decision tree using a numerical algorithm or another logic device control: uses sensors, a data acquisition system, and digital control (for example, if pressure is >P and if temperature is < T and experiment duration is > t, then do X).

5. Action based on a complex set of conditions, qualitative and quantitative considerations, all of which can be anticipated in advance: experiment control utilizes an expert system based on heuristic inference engine possibly in conjunction with numerical models. This option requires a good understanding of all the possible experiment outcomes in order to develop a knowledge-based set of rules.
6. Action based on a complex set of conditions not anticipated in advance but that can be extrapolated from previous experience: the control system may utilize an adaptive neural network initially in a "supervised learning" mode that is "trained" to control the experiment.

The level of control complexity appropriate depends on the level of maturity of the experiment. The GGSF modular computer will allow for the implementation of AI and artificial neural network if necessary. The control rationale and software will be developed in the laboratory and loaded into the computer.

Level 1 in the list above may not be available during MTC and may be better suitable for PMC. In general, levels 2 through 4 will be appropriate for most experiments. The capability to upgrade the experiment control into levels 5 and 6 is provided by the GGSF modular computer concept.

Mission Operations.

During MTC, the space shuttle docks every 90 to 180 days, for 7 to 10 days. During that time the astronauts must perform any required maintenance operation. These occasions will also be used for hardware reconfiguration and replenishment of consumables as required. Due to such activities this is a nonquiescent time and it must be considered whether experiments are affected by the induced environments. Because of their assignments to such activities, it is unclear how much time the astronauts will actually have to dedicate to operating the facility and conducting experiments. The quiescent environment between such Shuttle docking provides a better experiment environment. During the quiescent period there is no operator to operate the payload and full automation or remote control is required.

During MTC phase the sequence of experiments will be to conduct one experiment repeatedly or to perform more than one or a few experiments. If more than one experiment is performed, all interfaces to the chamber must be validated prior to the start of automated operations. Only experiments that are compatible with the hardware configuration and selected (interchangeable) subsystems can be performed in one sequence. The timeline of each experiment must be developed to determine the appropriate sequence.

Overall GGSF layout

Figure 4 shows the GGSF conceptual design layout.

References

[1] Gas Grain Simulation Facility: Fundamental Studies of Particle Formation and Interactions. Vol. 1 and 2. Edited by G. Fogleman, J.L. Huntignton, D.E. Schwartz, and M.L. Fonda. Proceedings of a workshop held at NASA Ames Research Center. NASA Conference Publication 10026, 1989.

[2] NASA/ESA/NASDA Agreement, Amended. Payload Interchangeability. Undated.

[3] SSP 30426, Rev. B. July 1991.

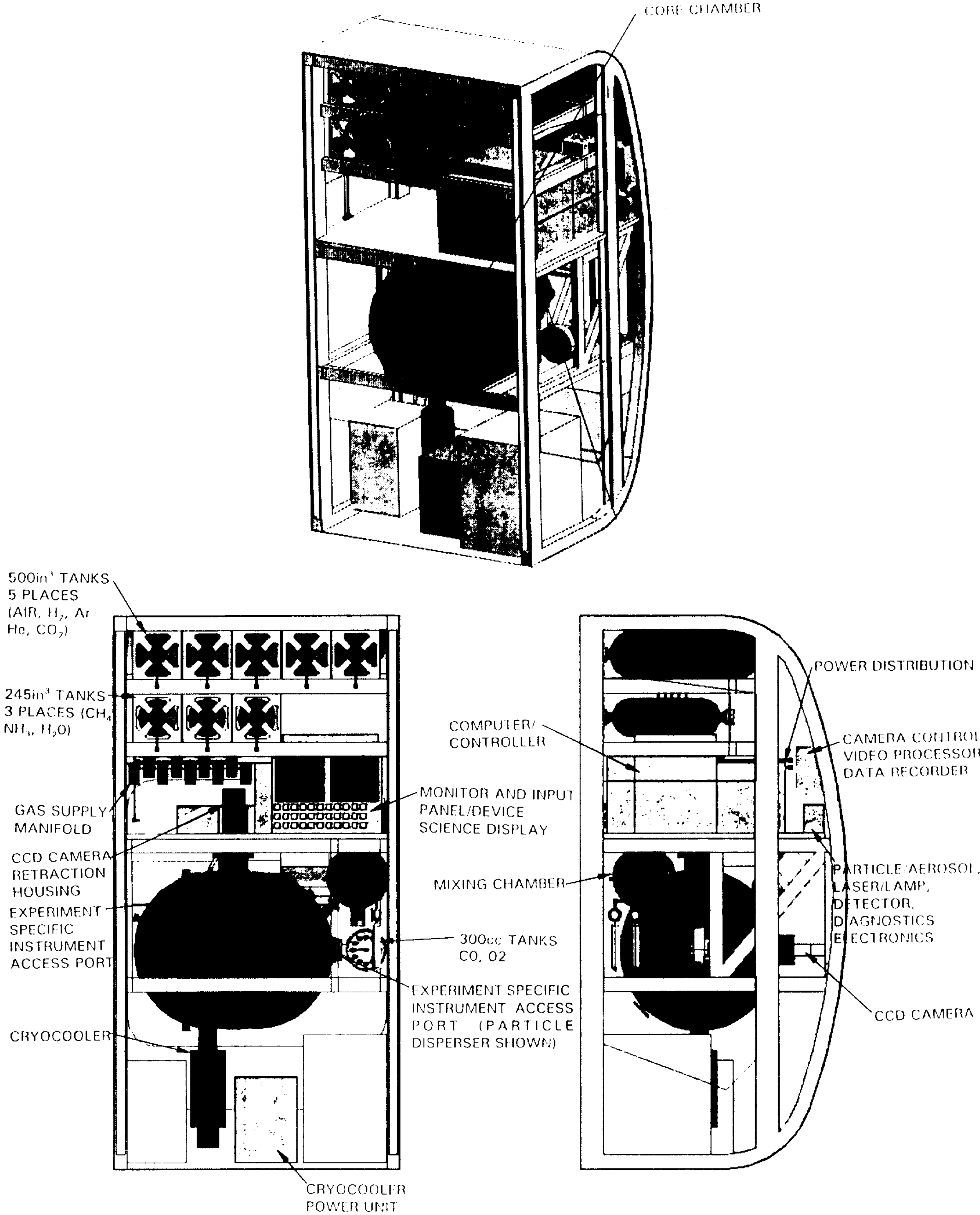

Figure 4. Overall GGSF layout

Appendix F

Potential for Spectral Range for the GGSF

The following suggestions were made after the GGSF Science Workshop (May 4–6, 1992) by Dr. Thomas Wdowiak of the Department of Physics, University of Alabama at Birmingham, on the spectral requirements for the GGSF:

The spectral properties discussion session document utilized for the Las Vegas GGSF workshop stated a spectral range requirement of "about 0.2 µm in the UV to about 30 µm in the IR." These requirements were drawn from the strawman experiments originating from the 1987 meeting. It is important to consider what a practical and economical range capable of accommodating a broad family of experiments can be. This note will address the range question from the standpoint of astrophysical questions.

1. The GGSF has potential for investigation of the nature of interstellar matter responsible for the character of the interstellar extinction curve. Interstellar extinction increases as one progresses from the visible into the ultraviolet. There is a distinctive broad feature that "peaks" at 0.2175 µm followed by an increase at shorter wavelengths.[1] The spectral characteristics of a material at wavelengths below 0.2 µm are an important consideration in being able to fit laboratory spectra to the astronomical observations.

   Most "table-top" laboratory spectrometers have a short wavelength cut-off of 0.19 µm not because of instrumental limitations, but because the chemist user community generally does not purge its instruments with a gas such as nitrogen. Thus a short wavelength of "about 0.2 µm" for GGSF spectroscopy is artificial and not representative of what is possible without extreme effort and expense. In terms of windows or light source envelopes, fused silica can be utilized down to 0.157 µm [2] while sapphire (Al_2O_3) has a shorter wavelength cut-off of 0.1425 µm.[3] Sapphire is now used for flashlamp envelopes suggesting that it can have utility in replacing fused silica as the envelope of a high-pressure xenon lamp. Using conventional deuterium or xenon lamps, a CW continuum is obtainable down to 0.1675 µm. Using MgF2 windowed deuterium lamps which are "off the shelf" a continuum is obtainable further down to 0.11µm. Compatible detector technology, windows, and sources make GGSF

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[1] Zombeck, M.V., *Handbook of Space Astronomy and Astrophysics*, 1990.

[2] Dunkelman, L., W.B. Fowler, J. Hennes, "Spectrally Selective Photodetectors for the Middle and Vacuum Ultraviolet", *Applied Optics* Vol. 1, p. 965–700, 1962.

[3] Laufer, A.H., J.A. Pirog, J.R. McNesby, "Effect of Temperature on the Vacuum Ultraviolet Transmittance of Lithium Fluoride, Calcium Fluoride, Barium Fluoride and Sapphire", *Journal of the Optical Society of America*, Vol. 55, p. 64, 1965.

spectroscopy down to about 0.15 µm very easy and down to 0.11µm possible; astrophysical considerations alone suggest its desirability.

2. Astronomical observations at wavelengths greater that 30 µm are yielding data regarding condensed state (grains) interstellar matter. Emission in the 40–70 µm region by H_2O ice that appears to be crystalline at $T \geq 50$ K is an example.[4] Also, certain carbon-rich stars exhibit a broad emission feature that extends out to 50 µm and has been attributed to a MgS grain component in circumstellar shells.[5] Because FTIR is the technique of choice at infrared wavelengths, the spectrometer used for measurements in the 2–25 µm range can be adapted to longer wavelengths by substituting the KBr beam-splitter and windowed pyroelectric detector with a Mylar beam-splitter and high density polyethylene windowed pyroelectric detector. A globar source used for the 2–25 µm range can also serve out to 100–150 µm. Use of a high pressure mercury vapor lamp with a quartz envelope would allow measurements at even larger wavelengths, however, safety consideration may preclude its use. As in the UV situation it appears IR spectroscopy beyond 30 µm and out as far as 100–150 µm can be accomplished without extreme effort and expense. Astrophysical considerations warrant exploration of the possibility.

3. FT-Raman appears to be a spectroscopic technique not considered in any of the strawman experiments. Omission of FT-Raman as a diagnostic available for the GGSF can have significant ramifications for the use of the Facility. Raman spectroscopy is very important in the [6]study of diamond-like carbonaceous material, serving to characterize such materials in a manner impossible for IR spectroscopy. It has found extensive utility in characterizing interplanetary dust particles (IDPs) and soot simulants of interstellar dust giving rise to the unidentified infrared (UIR) emission bands. Because of its non-appearance in the strawman experiments and non-discussion at the Las Vegas meeting, Raman is in danger of being neglected by circumstance.

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[4] A. Omont, S.H. Moseley et al, "Observations of 40–70 Micron Bands of Ice in IRAS 09371+1212 and Other Stars", *The Astrophysical Journal*, 355:L27–L30, 1990, May 20.

[5] J. H. Goebel and S.H. Moseley, "MgS Grain Component in Circumstellar Shells", *The Astrophysical Journal*, 290: L35–L39, 1985 March 1; J.A. Nuth, S.H. Moseley et al, "Laboratory Infrared Spectra of Predicted Condensates in Carbon-rich Stars", *The Astrophysical Journal*, 290: L41–L43, 1985, March 1.

[6] L.J. Allamandola, A.G.G.M. Tielens and J.R. Barker, "Polycyclic Aromatic Hydrocarbons and the Unidentified Infrared Emission Bands: Auto Exhaust along the Milky Way", *Astrophysical Journal*, 290: L25–L28, 1985, March 1.

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13. ABSTRACT *(Maximum 200 words)*

This document reports on the proceedings of the GGSF Science Workshop which was co-hosted by NASA Ames Research Center and Desert Research Institute, University of Nevada System, and held in Las Vegas, Nevada, on May 4–6, 1992. The intent of the workshop was to bring together the science community of potential GGSF experimenters, Science Working Group and staff members, and the Phase A contractor to review the Phase A design with the science participants and to facilitate communication between the science community and the hardware developers. The purpose of this report is to document the information disseminated at the workshop, to record the participants' review of the Phase A GGSF design concept and the current science and technical requirements for the Facility, and to respond to any questions or concerns that were raised at the Workshop. Recommendations for the future based on numerous discussions with the participants are documented, as well as science presentations and poster sessions that were given at the Workshop and a summary of 21 candidate experiments.

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